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(FOR ARTICLES ON THE GEOLOGY OF EAST ANGLIA)

NO. 63 2013

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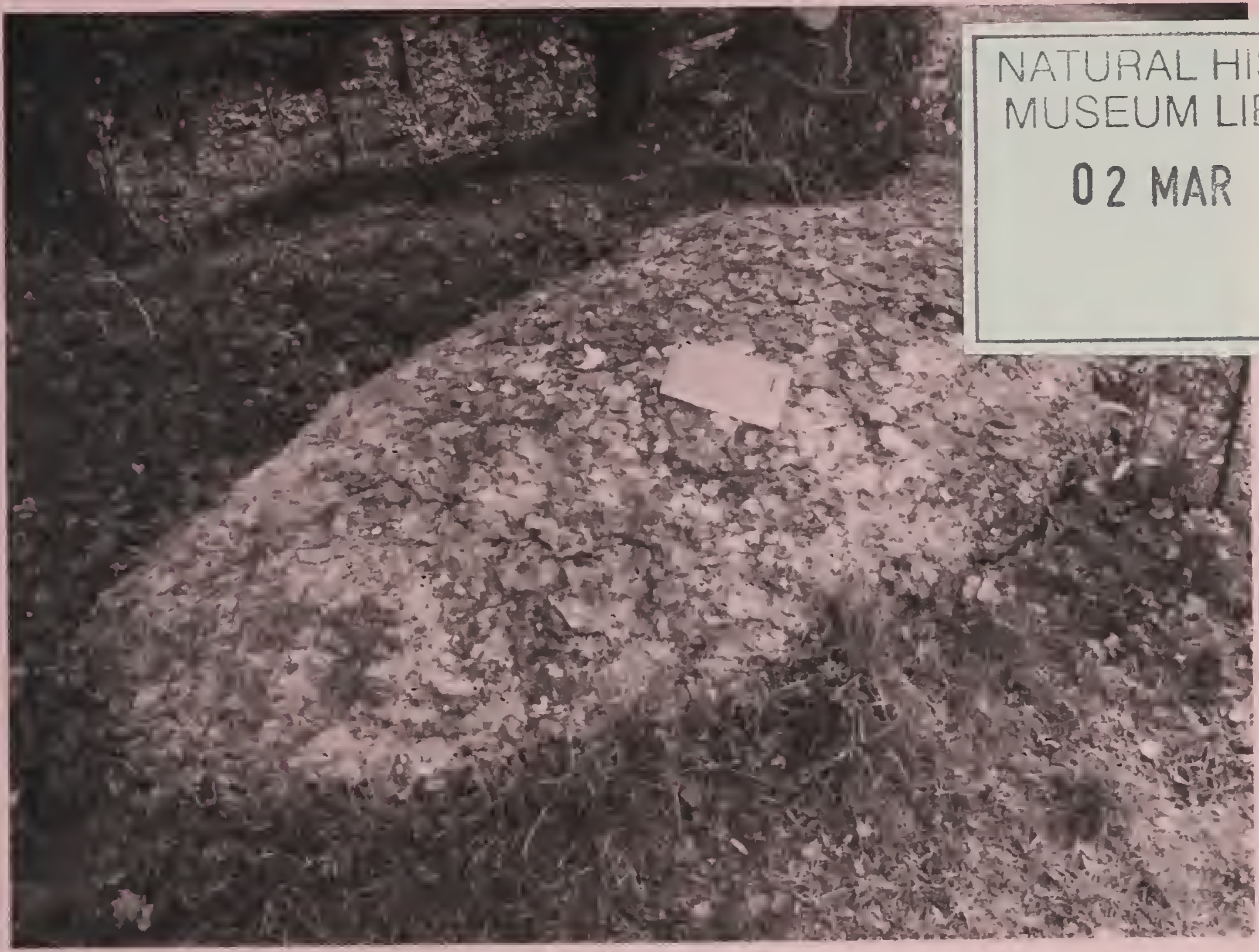

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William Smith in Norfolk and Suffolk

Frederic William Harmer, Pioneer Palaeometeorologist

Jurassic Oysters in Glacial Erratic, Oxburgh Hall

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BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK
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EDITORIAL

This issue of the Bulletin, by happy coincidence, contains two papers on historical geology, both built around geologists of some repute. Many of us are well aware of the importance of William Smith to geology, but probably most of us link him geographically with the west of England. Peter Banham's article covers a rather less well known part of Smith's life, when he worked for more than a decade in Norfolk and Suffolk, employed doing what we would consider today, as sustainable solutions to sea defence. In the second article, John Kington describes the late Victorian 'Norwich geologist' Fredric Harmer, outlining his contributions and most interestingly highlighting his pioneering work on palaeometeorology. Kington directly compares Harmer's reconstructions of northern hemisphere atmospheric circulation patterns for the last glacial period with those made in the mid-1960s by Hubert Lamb. It is of course fitting that palaeometeorology has its geological roots in Norwich, where, in 1972, Lamb became first director of the Climatic Research Unit (CRU) at the University of East Anglia: the CRU celebrated its 40th birthday last year. It is also fitting to observe that both palaeoclimatology, through the CRU link, and sustainable sea defences connect directly to the founding Dean of the UEA's School of Environmental Sciences, Professor Keith Clayton, who died earlier this year (see obituary on pages 3-4).

INSTRUCTIONS TO AUTHORS

Contributors should normally submit manuscripts either as word-processor electronic files (MS Word is preferred) or hard copy. When papers are accepted for publication we will request an updated electronic version.

It is important that the style of the paper, in terms of overall format, capitalization, punctuation etc. conforms as strictly as possible to that used in Vol. 53 of the Bulletin. Titles and first order headings should be capitalised, centred and in bold print. Second order headings should be centred, bold and lower case. Text should be 1½ line spaced. All measurements should be given in metric units.

References should be arranged alphabetically in the following style.

BALSON, P.S. & CAMERON, T.T.J. 1985. Quaternary mapping offshore East Anglia. *Modern Geology*, **9**, 221-239.

STEERS, J.A. 1960. Physiography and evolution: the physiography and evolution of Scolt Head Island. In: Steers, J.D. (ed.) *Scolt Head Island* (2nd ed.), 12-66, Heffer, Cambridge.

BLACK, R.M. 1988. *The Elements of Palaeontology*. 2nd Ed., Cambridge University Press, Cambridge. 404pp.

We hope to make pdf versions of all papers from now on to serve as offprints for authors and for possible future WWW availability. For this reason we prefer illustrations drawn with a computer graphics package, ideally saved in jpeg format. Thick lines, close stipple or patches of solid black or grey should be used with care as they can spread in printing hard copy. The editor may have diagrams re-drawn professionally and usually the GSN will cover the cost of this. For efficient use of space full use should be made of the width of print on an A4 page when designing diagrams. Half tone photographic plates (if possible reproduced as jpeg files) are acceptable provided the originals exhibit good contrast.

The editors welcome original research papers, notes, comments, discussion, and review articles relevant to the geology of **East Anglia** as a whole, and do not restrict consideration to articles covering Norfolk alone. All papers are independently refereed by at least one reviewer.

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OBITUARY

Keith Michael Clayton CBE (1928-2013)

Keith Clayton, Honorary President of the Geological Society of Norfolk in 1975 died on February 12, 2013, at the age of 84. His impact on earth science research and education in East Anglia was highly significant in a number of ways.

Arguably the key moment in Keith's career was his decision to accept the challenge of setting up a School of Environmental Sciences at the fledgling University of East Anglia (UEA) in Norwich. With a co-founding geologist, Professor Brian Funnell, he set out to design a new interdisciplinary approach to studying the Earth, its surface processes, biological systems and interactions with humans. He became the founding Dean of the new School in 1967. The discipline of Environmental Science was virtually unheard of 45 years ago, so setting up a centre to research and teach this new subject was truly radical. Indeed the established science world was dismissive, in fact quite rude about this new interdisciplinary approach. The School, however, soon became internationally renowned, and many of the critics slowly became converts to the new ways of thinking and redesigning their university departments. Keith also took a key decision in 1971-2 in helping set up the Climatic Research Unit (CRU) at UEA. Tellingly, he recruited the renowned climatologist Hubert Lamb from the UK Meteorological Office to lead it. CRU is today recognised as one of the world's premier institutions researching natural and anthropogenic climate change. Once again Keith had the foresight to see the potential in such science, long before it became main-stream.

Keith completed his PhD 'The Quaternary of Southern Essex' in 1958 at the London School of Economics, describing research that centred on glacial erosion and landforms in southern Essex. By the late 1960s, already an established figure in geomorphological research, Keith became interested in utilising the newly emerging remotely sensed images from satellites. He understood the importance of being able to quantify processes such as glacial and coastal erosion, and he realised that computers were vital to assemble and process the massive datasets required.

Much of his varied research was based in East Anglia. He strongly advocated allowing natural coastal processes to operate unhindered as a far as was practicable, a champion of coastal 'managed realignment', long before the term became common to scientists and public alike. He believed that healthy sand-rich beaches, fed by natural erosion and deposition cycles, are a more sustainable coastal defence than concrete sea walls; the latter he viewed largely as "... intrusions into a mobile geological landscape" (Clayton 1976). His views were not welcomed by engineers or by many coastal communities in East Anglia, even though he was an early advocate of 'social justice' through appropriate compensation.

Keith was an advisor to government departments on environmental matters, and helped shape international environmental change strategies. In 1984 he received a CBE for services to the University Grants Committee and UEA. In the vanguard of modern quantitative geomorphology, his scientific contributions were recognised in 1989 with the award of the Patron's Medal of the Royal Geographical Society.

Keith was a long standing GSN member and contributed two articles to the Bulletin (Clayton 1976 and Clayton 2000), becoming a regular attendee at evening meetings in his retirement years.

As an earth scientist of national standing, more complete obituaries have been published in the Independent (26 February 2013), Times (8 March 2013), Telegraph (26 May 2013) and the Eastern Daily Press (20 February 2013).

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JURASSIC OYSTERS IN GLACIAL ERRATIC AT OXBURGH HALL WEST NORFOLK

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ABSTRACT

A boulder in the grounds of Oxburgh Hall, west Norfolk, is made almost exclusively from shells of the Middle Jurassic oyster Praeexogyra hebridica *Forbes. An estuarine Middle Jurassic depositional environment can be inferred and it is likely the boulder originated from Blisworth Limestone Formation (Great Oolite Group) bedrock in the East Midlands. The boulder is interpreted as a glacial erratic and its current location, relative to its likely bedrock source, suggests transport by ice flowing broadly from the north-west. Unfortunately the glacial geological context of this boulder is not known, precluding further interpretation of its significance.*

INTRODUCTION

This short article describes a prominent boulder found at National Trust owned Oxburgh Hall (NGR TF 742012, Fig.1). The boulder can be found in the far NW corner of the wilderness area of the gardens (NGR TF 74032 01265) and has for many years been known colloquially as the ‘Roman Oyster stone’. This name is partly accurate as the boulder is composed almost entirely of flat oysters, but the ‘Roman’ association is rather more fanciful, the oysters being here identified as *Praeexogyra hebridica* Forbes of Middle Jurassic age.

The boulder was apparently dredged from the nearby river Wissey about 50 years ago and moved to its present location. Recovery from a river is important information as quarried blocks of stone were moved about fenland by barge in historical times for use in cathedrals and potentially also in large houses (Blanchford

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2004). A pertinent example being the Middle Jurassic 'Alwalton Marble' exposed in the banks of the river Nene at Alwalton and transported to Peterborough Cathedral, and elsewhere, by barge.

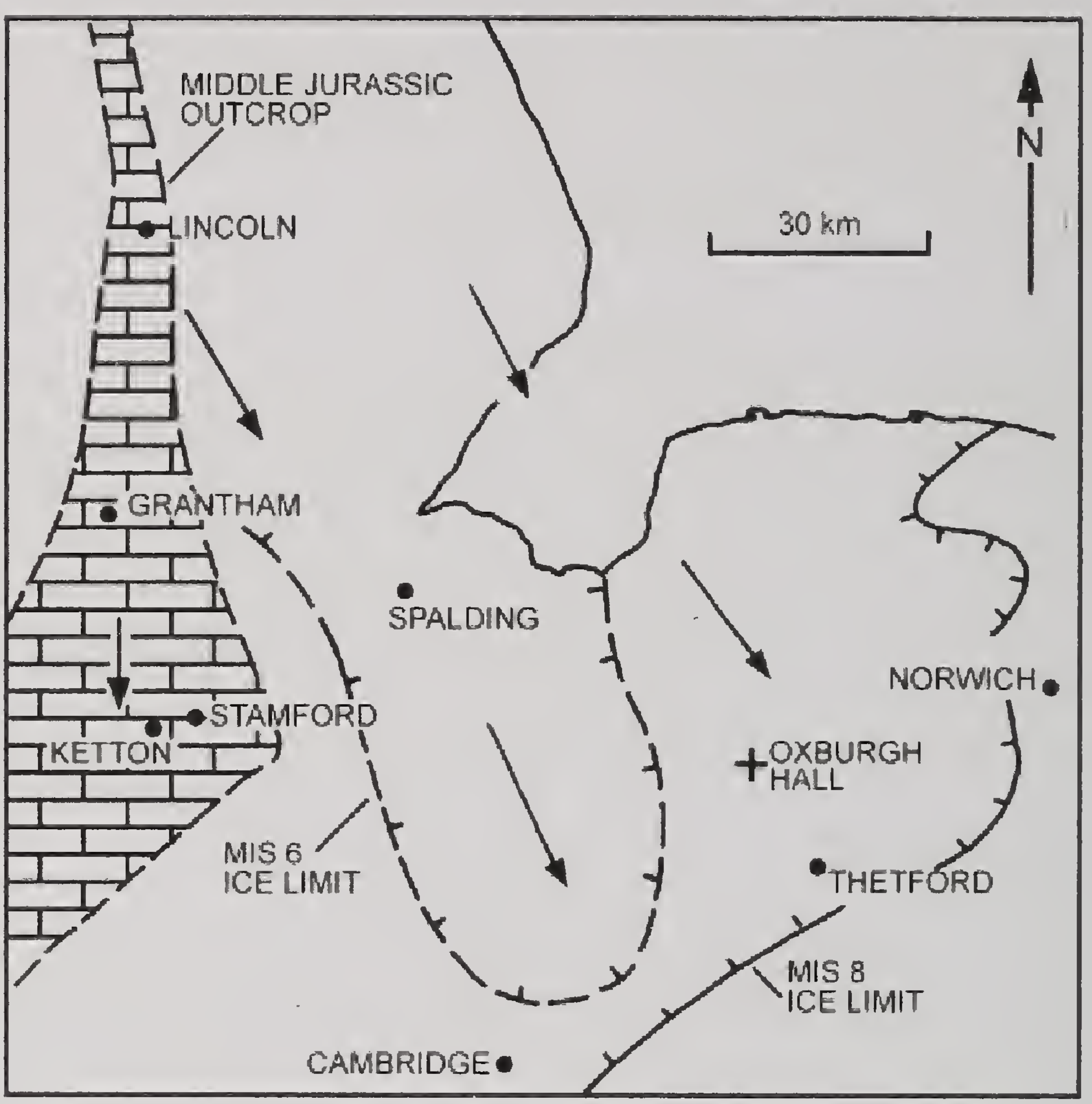

Fig. 1. Map showing the location of Oxburgh Hall in eastern England. The map also shows examples of inferred ice margin position for Marine Isotope Stage (MIS) 8 (Straw 2012) and MIS 6 (Gibbard et al., 2009). The inferred ice flow directions (arrows) pertain to MIS 8 only and are based on Straw (1983; 2012). The location of the boulder at Oxburgh Hall is consistent with derivation from Middle Jurassic bedrock (brick pattern) to the north west, probably from the Lincoln area. Alternative views on ice margin positions are given in Westaway (2010) and Langford (2012).

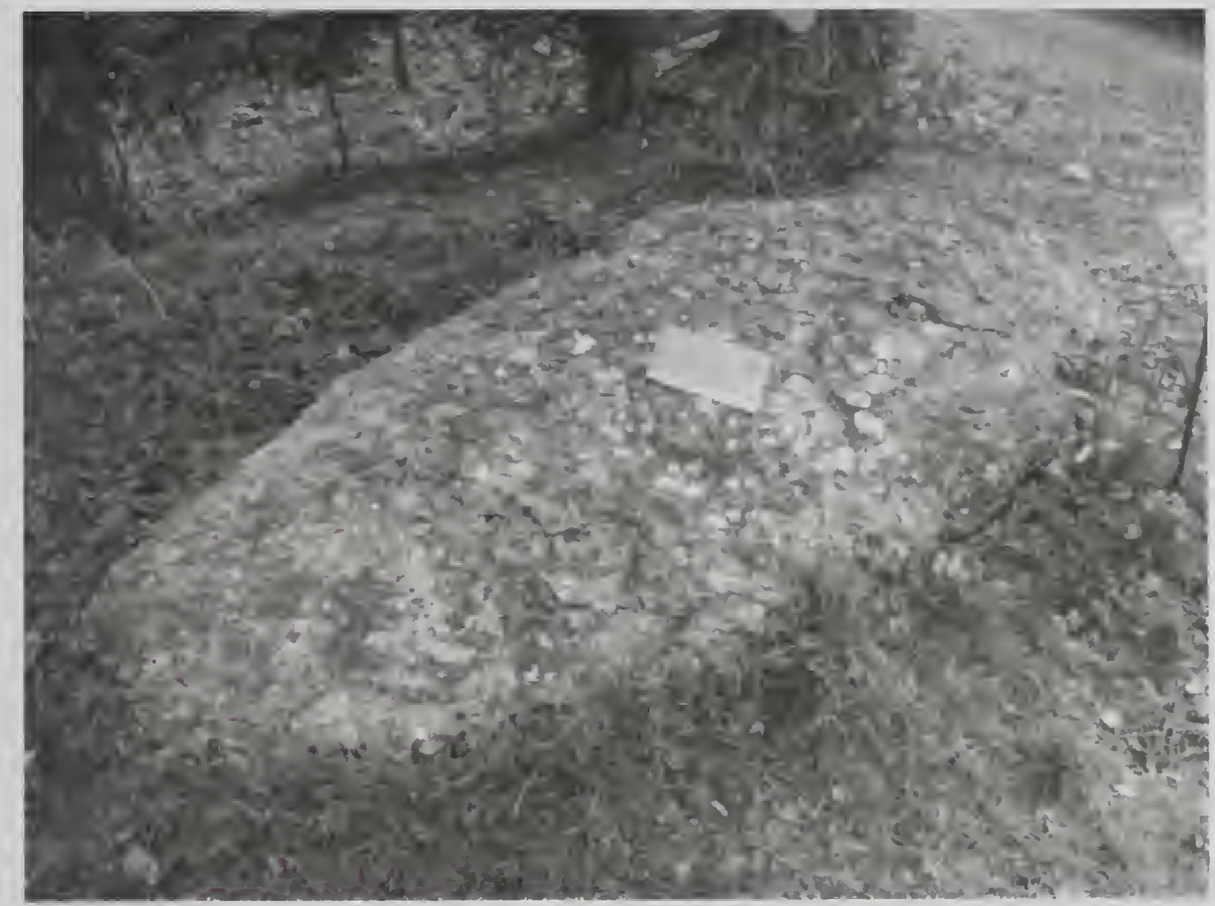

Fig. 2. Field photograph of the boulder, showing its rounded appearance. Field notebook for scale (20 cm long axis).

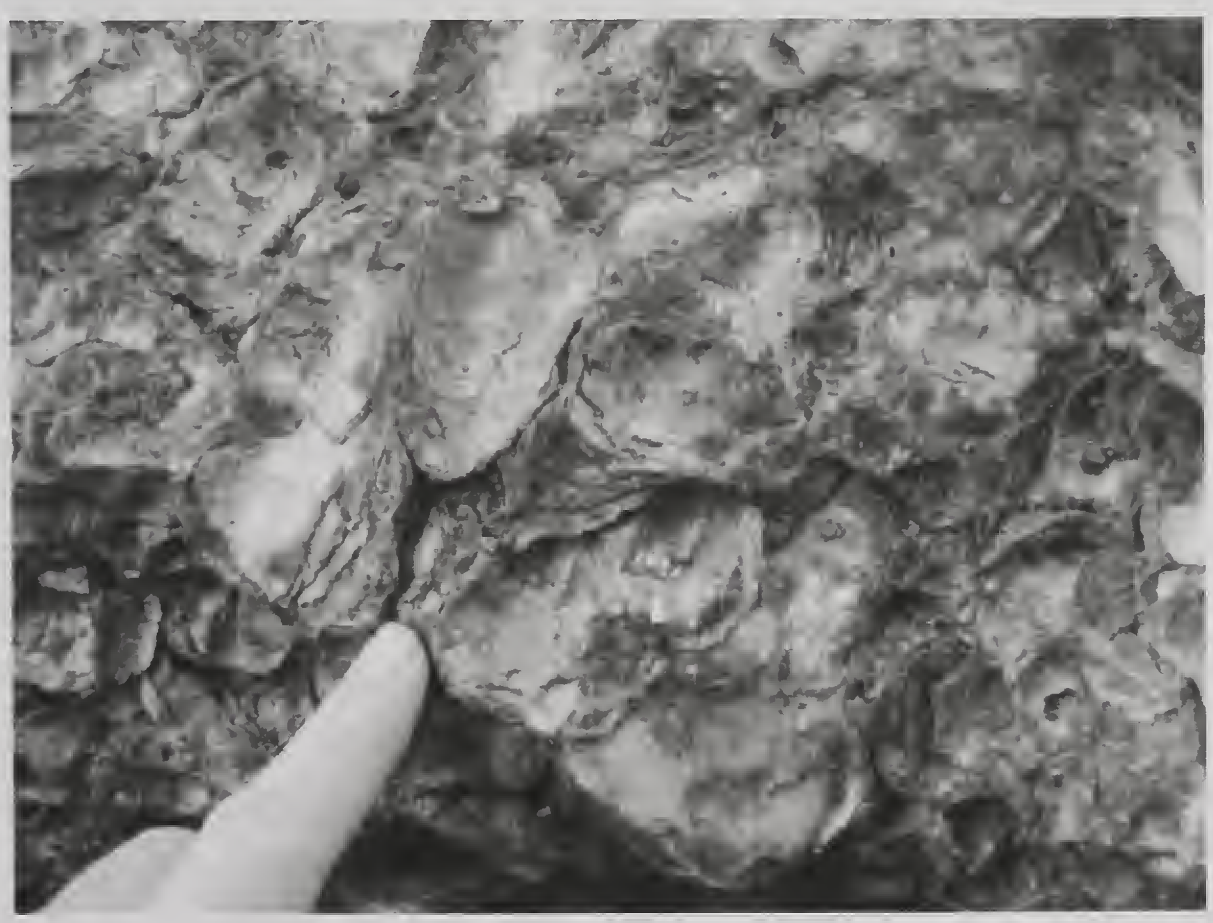

Fig. 3. Field photograph close-up of the rock forming oyster *Praeexogyra hebridica* Forbes. Finger nail is 10 mm wide.

However, in this case the rock type is entirely unsuitable for building as decorative stone, and moreover the boulder is quite well rounded (Fig. 2), unlike a quarried block which would be angular, typically with clearly worked surfaces. On this basis it seems likely the boulder is a glacial erratic, the local bedrock being Cretaceous Chalk not Middle Jurassic limestone. Others have similarly interpreted this boulder as a glacial erratic (M. Burgess; The Stone Index, http://www.hiddenea.com/stoneindex.htm).

BOULDER DESCRIPTION

The boulder is about 2.5 m x 1.2 m x 0.6 m (thick) and composed almost entirely of *Praeexogyra hebridica* Forbes of Middle Jurassic age (about 165 million years old). The oysters are typically 7 cm long and 6 cm maximum width, although the largest shells are up to 12 cm long and 7 cm maximum width (Fig. 3). The oysters are mostly whole, in sub-horizontal orientation, showing little evidence of breakage, comminution or boring by other organisms. No other fossils were seen in the boulder. The boulder shows very low-angle crudely arcuate stratification, each layer only the thickness of a few shells (Fig. 4). The oysters are lightly cemented together and any spaces between shells are typically filled by a greenish-grey clay matrix. Despite the light cementation there is no clear evidence, at least in hand specimen, of burial diagenetic sparry-calcite cementation between shells.

INTERPRETATION: JURASSIC ENVIRONMENT

P. hebridica is interpreted as a marine euryhaline bivalve (Hudson and Palmer 1976) and it is often found in monotypic shell beds (e.g. Hudson 1980; Andrews and Walton 1990). Euryhaline organisms are well adapted to coping with environments where salinity fluctuates rapidly, often on a tidal cycle, for example in estuaries. It is inferred that *P. hebridica* was well adapted to living in 'estuarine' conditions, so much so that most other marine organisms were excluded. The very low-angle, crudely, arcuate bedding probably reflects the internal structure of low-relief banks. These banks would have trapped detrital clay and the pseudofaeces of the oysters themselves (Palmer 1979; Andrews and Walton 1990). The oysters are not clearly articulated, suggesting the bedding resulted from shell disaggregation and gentle hydrodynamic sorting rather than preservation of a 'living build-up'. The lack of vertical packing of shells, which can be caused by surf-dominated tidal reworking (Greensmith and Tucker 1968; Grinnell 1974; Ensom 1984) suggests relatively low-energy conditions with weak tide or wave action, consistent with interpretations for similar British Middle Jurassic facies (Palmer 1979; Hudson 1980; Andrews and Walton 1990).

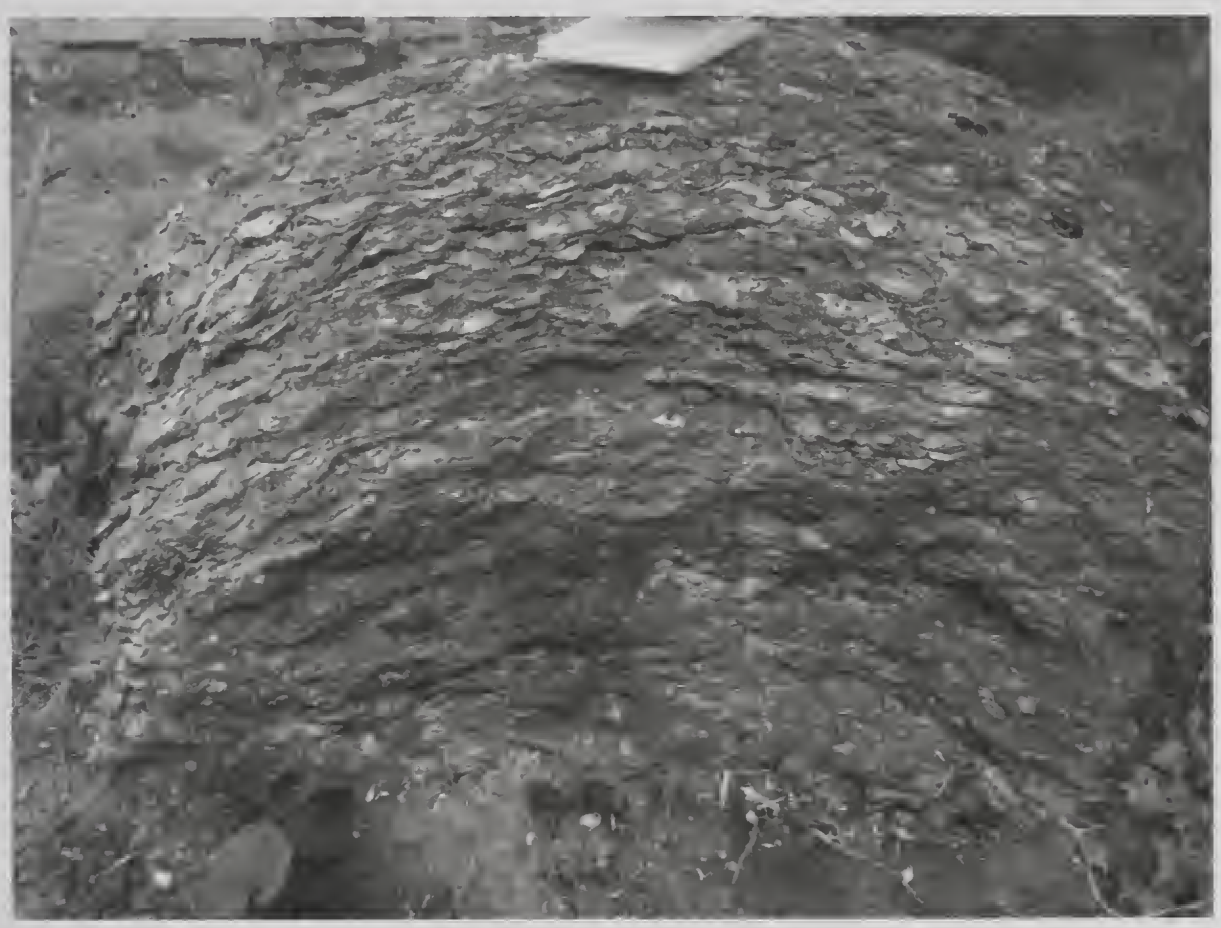

Fig. 4. Field photograph of the boulder showing crudely arcuate stratification. Field notebook for scale (20 cm long axis).

GLACIAL ERRATIC

If the source of this glacial erratic can be established, it should provide information on likely directions of ice movement. However, as the glacial geological context of this boulder is not known it is unwise to speculate in great detail on its significance.

While it is not possible to be certain where this boulder originated, we know the closest outcropping Middle Jurassic rocks are exposed in a narrow band in the East Midlands, roughly on a gently curved line between Northampton in the south, Stamford in the centre and Lincoln in the north (Fig 1). It is highly likely the boulder originated from bedrock somewhere along this line. We also know, from the dimensions of the boulder itself, that the 'source oyster bed' was more than 60 cm thick, unusually thick for the East Midlands Middle Jurassic. It is likely the boulder originated from the Blisworth Limestone Formation (Great Oolite Group). For example in Grange Top cement quarry at Ketton (Rutland; Fig. 1), the Blisworth Limestone contains a 1.3 m shell bed made almost entirely of this distinctive oyster (Hudson and Clements 2007). This bed, or one very like it, was almost certainly the source of the boulder. The slightly older Rutland Formation that underlies the Blisworth Limestone contains some similar oyster beds, which could equally be the source, but these beds are typically thinner than 60 cm where recorded at outcrop.

There is existing evidence in this region for Late Pleistocene ice flow broadly from the NW to the SE. For example, Gallois (1978) inferred a north westerly source for the oldest Chalky-Jurassic Till in West Norfolk. Moreover discussions about possible ice extent and flow directions in the area during Marine Isotope Stage (MIS) 8 (Straw 1983, 2011; Westaway, 2010) or MIS 6 (Gibbard *et al.*, 2009; Langford 2012), are also broadly consistent with a SE direction of transport. This ice flow information strongly suggests the bedrock source location was Blisworth Limestone in the Lincoln area, with ice crossing modern day Fenland in the area around Spalding (Fig. 1). Derivation from bedrock much further south than Lincoln would imply a more easterly ice flow which is not supported by the work of Straw (1983) in relation to MIS 8, who showed evidence for ice flow more or less due south in the Ketton and Stamford area (Fig. 1).

ACKNOWLEDGEMENTS

Many thanks to Angus Wainwright who initially asked me to look at this boulder for the National Trust. Jim Hendry, Harry Langford and Allan Straw gave very helpful discussion and comment on various aspects of the work. Phillip Judge produced the final version of Figure 1.

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[Manuscript received 12 July 2012; revision accepted 24 July 2012]

FREDERIC WILLIAM HARMER: GEOLOGIST AND PIONEER PALAEOMETEOROLOGIST

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ABSTRACT

Frederic William Harmer was born in Norwich on 24 April 1835. At the age of 15 he joined the Harmer family business (one of the oldest clothing manufacturing firms in the country) and in due course became its Director. A separate strand in Harmer's career, his interest in geology and the main theme of this paper, also emerged during his early years. He became an active member of the Norwich Geological Society and a chance meeting with the renowned geologist, Searles V. Wood, Junior, further advanced Harmer's geological interests. His mainly forgotten studies as palaeometeorologist in which he pioneered the reconstruction of past circulation patterns comprises an integral part of this paper. Harmer was a founder member of the Norfolk and Norwich Naturalists' Society (later its president, 1877-1879); a member of the Geological Society of London council (1896-1900); a member of the Palaeontographical Society council (1878-1882; 1905-1906); awarded the Murchison Medal (1902); and awarded an Honorary M.A. by the University of Cambridge (1918). His civic duties in Norwich included serving as Alderman (1880), Magistrate (1884) and Mayor (1887-1888). Harmer died in Cringleford on 11 April 1923, aged 87.

Bull. geol. Soc. Norfolk (for 2013), **63**, 13- 42.

INTRODUCTION

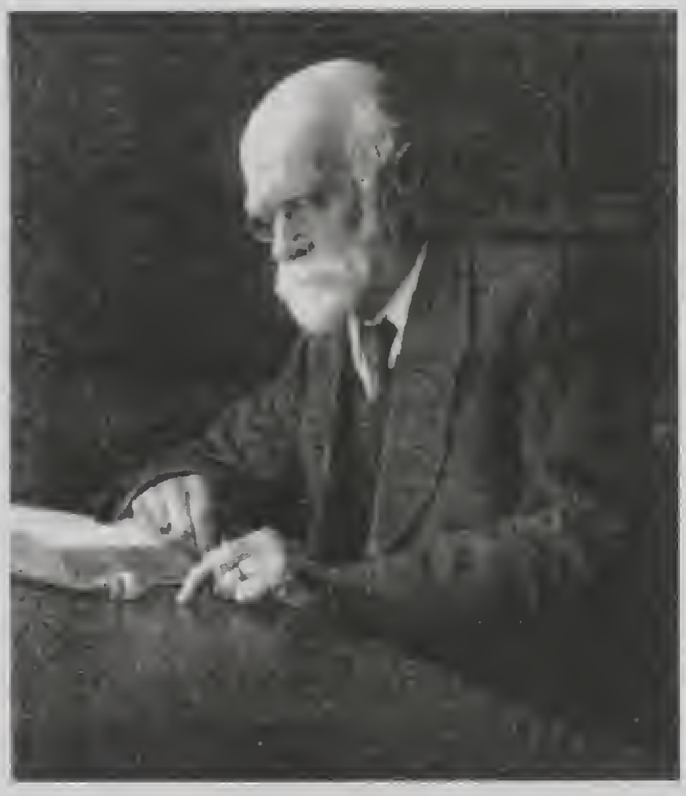
Frederic William Harmer (Fig. 1), besides being a successful Norwich businessman, was also a geologist and pioneer palaeometeorologist whose scientific work, now regrettably mostly overlooked, deserves to be more widely known today. For instance, it is inexplicable that no references are given to his research on East Anglian Crags in the current literature including *Geology of England and Wales,* Geological Society, London, 1992, and *British Regional Geology: London and the Thames Valley,* H.M.S.O., London, 1996. He was a well-respected scientist in his day, an active member of the Norwich Geological Society, awarded Hon. M.A. Cantab., and elected F.G.S. and F.R.Met.S. Later in his career (1902) he was awarded the Murchison Medal of the Geological Society in recognition of his work on the Pliocene and other deposits of East Anglia. A leading exponent of 19th-century geological literature, Horace B. Woodward, F.R.S., F.G.S, included Harmer in a group of geologists who 'have added greatly to our knowledge of the structure of the [East Anglian Crag] deposits…' (Woodward, 1887).

Harmer was one of the last members of a distinguished group of amateur geologists who had been responsible for making major advances in the science during the Victorian era and early 20th century. Although due to his business commitments he had little time during his early years to develop his interest in geology, a chance meeting with the renowned geologist Searles V. Wood, Junior on Mundesley beach was the beginning of a friendship and geological partnership in which, for example, they prepared a map of the glacial deposits of Norfolk and Suffolk on a scale of 1 inch to the mile – said to be the first 'drift' map of its kind in the literature.

Sadly, after the publication of further material on the Pleistocene deposits of eastern England, Wood died in 1884. The loss of his friend and co-worker deeply affected Harmer and for a time he withdrew from active geological studies and devoted himself to municipal duties and politics. However, on discovering, after a gap of about ten years, that his views had found a sympathetic hearing from a group of younger geologists, he resumed an intensive study of the Tertiary and Quaternary deposits of eastern England and mainland Europe. A series of papers on the East Anglian Crags, which remain standard references for the subject, inaugurated a new chapter in the geology of the region; his contributions to glaciology and palaeometeorology during this later period were no less innovative. It is unfortunate that Harmer's pioneer contribution to palaeometeorology is not acknowledged in the current literature and it is this omission that provides one of the main reasons for this paper to be presented.

In journeys to mainland Europe, Harmer visited colleagues in France, Belgium, Holland, Denmark, Italy and Switzerland to discuss and examine fossiliferous specimens, including, for instance, the large collection assembled by the Belgian malacologist, Philippe Dautzenberg at the Royal Belgian Institute of Natural Sciences in Brussels.

During the final years of his life Harmer produced two outstanding works: firstly, a contoured map showing the distribution of erratics and drift in England and Wales (Harmer, 1928); and secondly his *magnum opus*, a two-volume monograph, *The Pliocene Mollusca of Great Britain* (Harmer, 1914-1919; 1920-1925); this latter work remains a standard reference on the subject in which he had meticulously examined and copiously illustrated the rich deposits of fossilized shellfish in Britain, especially those in northeast Essex and East Anglia. This massive achievement provides a fitting monument to his outstanding efforts as a geologist.



FREDERIC WILLIAM HARMER
1835 - 1923
(Life Story Newsletter Vol 20 No 2 - June 1997)

Fig 1. Frederic William Harmer (M. Harmer, 1998)

FAMILY BACKGROUND

Harmer, a descendent of a long-established Norfolk family, was born in Norwich in 1835. He was privately educated and in 1849 was awarded a "School Certificate" for 'Progress in General Knowledge'. One year later, the fifteen-year old began working as a clerk for his father, Thomas at the family clothing business in Norwich. At this time Harmer lived with his parents at 1 Newmarket Terrace (since re-named Albert Terrace) off the Newmarket Road, Norwich. In 1856 Harmer became a member of the Congregational Church in Princes Street, Norwich. In 1860 he married Mary Lyon and they moved into a rented house at Grove Place, Heigham in Norwich. They had five children, all born in Heigham, John Alexander (27 October 1860), Sidney Frederic (9 March 1862), Edith Mary (5 October 1864), Thomas Bertrand (15 November 1867) and William Douglas (25 August 1873).

The second son, Sidney, became a distinguished zoologist, President of the Linnaean Society (1927-1931) and was awarded the Linnaean Medal in 1934. Also he was Director of the Natural History Museum from 1919 until his retirement in 1927, invested as a Fellow, Royal Society (F.R.S.) and, in 1920, a Knight Commander, Order of the British Empire (K.B.E.). The youngest son, William, became a consulting surgeon at St Bartholomew's Hospital in London, specialising in diseases of the throat and nose. He was a pioneer in the treatment of throat cancer by radium at the Radium Institute, London.

Public Life

Besides being a successful businessman Harmer was scholarly and well-travelled, making several visits to mainland Europe. His varied lifestyle was maintained by the success of the family clothing business. However, Harmer was also an outstanding public-spirited person who played an active role in Norwich affairs, becoming an Alderman in 1880, a Magistrate in 1884 and serving as Mayor in 1887-1888.

Harmer was one of the founders of the Norwich Electricity Company. He was also a founder of the Norwich Young Men's Christian Association (YMCA) and was, for some years, its vice-president. He was a trustee of the Norwich Grammar School, now known as the King Edward VI, Norwich School. Harmer and Sir Peter Eade, M.D., F.R.C.P. (Mayor of Norwich 1883, 1893 and 1895) were jointly responsible for the layout of Chapel Field Gardens, the gardens surrounding Norwich Castle and the acquisition of Mousehold Heath.

Harmer took an active interest in the Norwich Geological Society, the Norfolk & Norwich Naturalists' Society and the Norfolk & Norwich Horticultural Society. He became an authority on the geology of East Anglia and was elected a Fellow of the Geological Society of London. Harmer was also a member of several geological societies in mainland Europe. Through his geological studies he became a pioneer of palaeometeorology and was elected a Fellow of the Royal Meteorological Society.

CONTRIBUTIONS TO GEOLOGY

East Anglia is a region unmatched in the British Isles for the study of lowland glaciation and in his geological research Harmer focussed his attention on this subject together with the Pliocene and Pleistocene deposits of eastern England. In his contribution, the historical work on the Crags is written using the age designations of Harmer's time. As explained at the end of this paper the modern Crag stratigraphy now recognises that the Red Crag and the Norwich Crag are of Pleistocene rather than Pliocene age.

The Distribution of Erratics and Drift

Co-ordinating observations made by glaciologists in England and Wales, Harmer showed the origin and movement of the ice-streams associated with the glacial deposits of the region by means of a contoured map. This was the first detailed map showing the distribution of erratics and drift in England and Wales on which Harmer used a system of symbols to indicate the respective sources of these features (Harmer, 1928).

Ice Age Chronology

When Harmer identified two or more layers of glacial boulder clay in Norfolk separated by interglacial sands he showed that the chronology of the Ice Age was more complex than had previously been proposed by Louis Agassiz in the 1830s. Harmer's finding preceded the more well-known views of James Geikie who also had suggested that instead of one single advance and retreat, the Ice Age had been marked by a series of alternating glacial and interglacial stages. Harmer's paper included reference to a glacial deposit exposed at a pit near the Trowse railway junction (one mile south of Norwich) which comprised stiff whitish clay, wholly unstratified, containing a great deal of chalk debris and occasional quartzose erratics (Harmer, 1867).

History of the Red Crag

The Red Crag, comprising quartz-rich sand stained orange-red with iron oxides, lies unconformably above the London Clay. It was this distinctive Pliocene formation deposited nearby to land in a warm and relatively shallow sea about 2.5 million years ago, that particularly interested Harmer. Its rich content of mostly broken and abraded fossilised shells indicate a highly energetic marine and atmospheric environment in which material from the sea bed had been repeatedly swept up onto contiguous shorelines due to a combination of powerful wave action and strong winds.

Harmer discovered that the earliest scientific account of Crag fossils had been made by the naturalist-geologist, Samuel Dale (1659?-1739) in the appendix of his book, *The History and Antiquities of Harwich and Dovercourt, first collected by Silas Taylor, and now much enlarged, with notes and observations relating to natural history,* London, 1730 (Challinor, 1971). Dale based his account on a letter to the *Philosophical Transactions of the Royal Society* in which he commented on the yet to be named Red Crag formation.

> *... why the same strata of sand, and fragments of shells, with the same fossils imbedded* [the Red Crag], *are to be found at Walton Ness on the other side of the Æstuarium* [Dovercourt Bay], *which is 5 or 6 miles broad from Harwich, as likewise at Bawdsey Cliff in Suffolk, which is 8 or 9 miles distant, and in other cliffs on that shore, where I have met with them* (Dale, 1704-1705).

This observation indicates that Dale was aware of the notable exposures of the Red Crag in the cliffs of northeast Essex and south Suffolk – later to be investigated by Harmer.

Dale included two plates in his book of the Harwich Cliff and four figures illustrating fossils he had described in the text. In the preface Dale acknowledged that that basis of the book had been set down by Taylor in about 1676. Following Taylor's death in Harwich two years later, Dale obtained and edited the manuscript with a view to its publication. Although the text, comprising 255 quarto pages, was compiled directly from Taylor's manuscript, the appendix was entirely Dale's work and contained his account of the geology of the Harwich Cliff which he described as 'a sort of promontory, which divided Orwell Haven from the *Æstuarium* [Dovercourt Bay] contained between that and Walton Naze or Ness'. Over 40 fossils from the Harwich Cliff described by Dale have now been classified under the Red Crag formation according to current terminology.

Dale also discussed the problem about the origin of fossils which had puzzled oryctologists for many years. For example, whilst the palaeontologist, Robert Plot held the view that they were *lapides sui generic*, produced by some plastic power inherent in the crust of the earth, Robert Hooke presciently believed that they owed their form and figuration to the shells of certain shellfish and believed that such fossils provided reliable clues to the past history of life on earth. Despite the objections of contemporary naturalists such as John Ray, who found the concept of extinction theologically unacceptable; Hooke stated that in certain cases they might represent species that had become extinct through some geological disaster.

Dale's account of the Red Crag fossils in the Harwich Cliff is especially valuable as it preserves a record of the contents of a former outlier of the Essex coast which was later lost to the sea. His name is preserved by a species of fossil shellfish, *Buccinum dalei* (Dale's whelk: *Liomesus dalei*). In naming it, James Sowerby (1757-1822), himself a student of the crag fossils, said he did so 'to commemorate the labours of Dale, who appears to be the first person that took notice of the Suffolk [sic] crag fossils'.

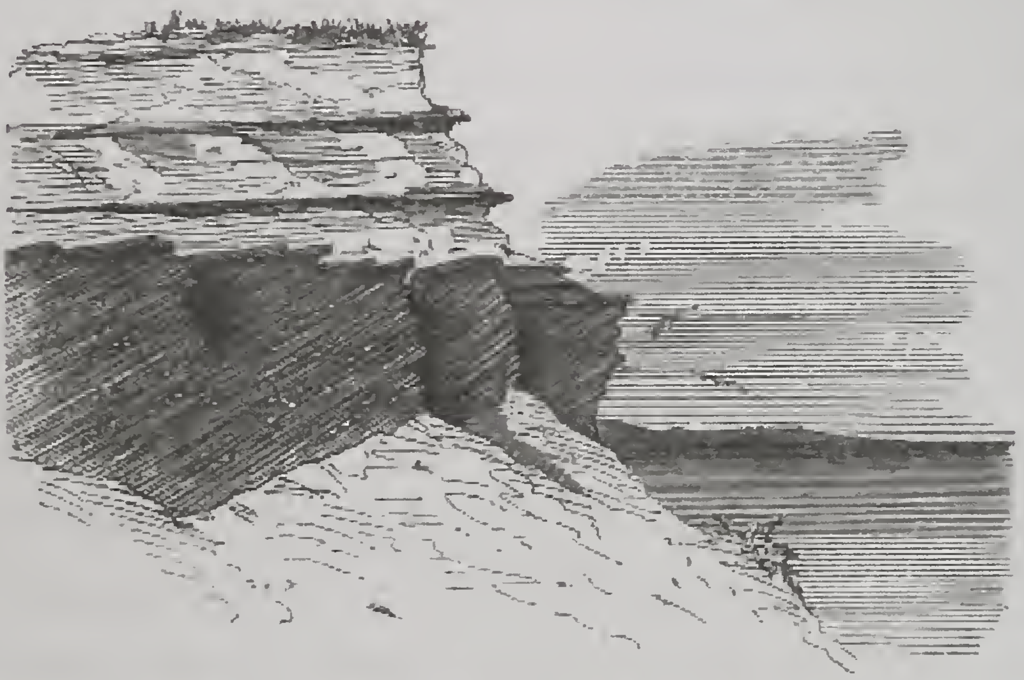
Following Dale's lead, Harmer found that much of the Red Crag was bedded at a more or less constant angle of 30° (Fig. 2), as, for example, in the cliff section at Walton-on-the-Naze. Harmer further discovered that the beds never attain any great thickness, generally not more than about 6 m (20 ft), but constantly present a highly inclined bedding pattern. Such stratification indicates, as pointed out by Wood, Jun., a deposit formed against a beach, or foreshore, or on the edges of a shoal.

In the early 1870s Wood, Jun. and Harmer presented a detailed account of the Red Crag:

The physical structure of the Red Crag is unlike that of any other formation known to us, ancient or modern. The more considerable portion of it is formed of a succession of beds, varying from two or three, to nearly twenty feet in thickness, each of which consists of laminae of sand and shells, inclined at a high degree to the horizon... This structure is altogether different from the well-known one of false bedding, which also exists in some parts of the Red Crag, especially in that under which the phosphatic nodules are worked, and the two forms of bedding pass more or less into each other. This oblique lamination may be traced (as, for instance, in Bawdsey Cliff) for a considerable distance in a constant manner, without shading off into horizontal stratification or passing into false bedding (Wood, Jun. and Harmer, 1872-1874).

In providing one of the best exposures of the Red Crag in the country, Bawdsey Cliff (Figs 2 and 3) is today a Site of Special Scientific Interest.

OBLIQUE RED CRAG IN BAWDSEY CLIFF.



The oblique bedded crag appearing above the Talus is nearly twenty feet in thickness.

Fig 2. A formation of the Red Crag in Bawdsey Cliff, Suffolk, typically showing the inclination of this obliquely bedded deposit at about 30° to the horizontal (Wood, Jun. and Harmer, 1872-1874)

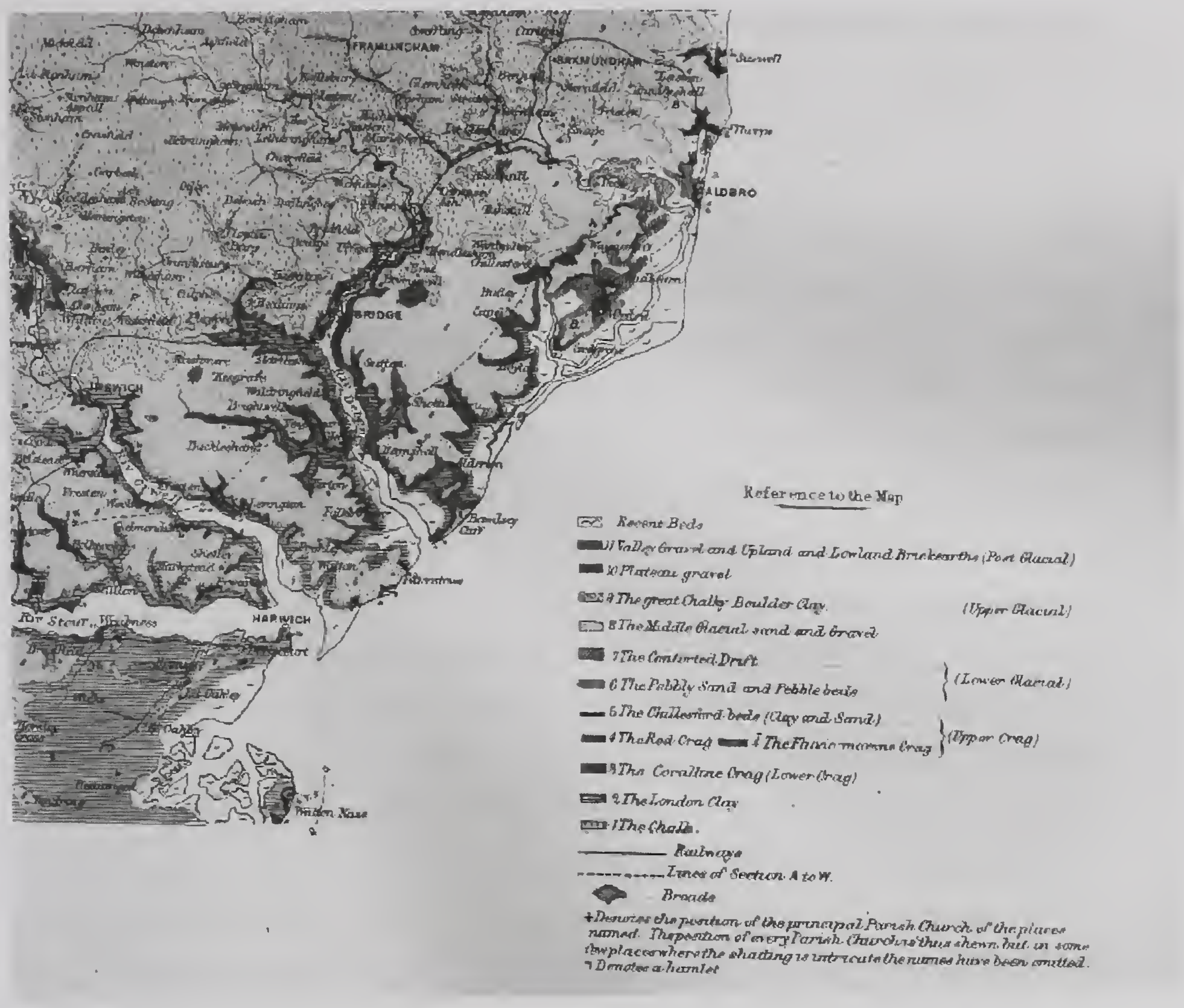

FRAMLINGHAM
SAXMUNDHAM
Sizewell
Thorpe
ALDBRO
IPSWICH
HARWICH
Bawdsey Cliff
Walton Naze
Reference to the Map
Recent Beds
11 Valley Gravel and Upland and Lowland Brickearths (Post Glacial)
10 Plateau gravel
9 The great Chalky Boulder Clay. (Upper Glacial)
8 The Middle Glacial sand and Gravel
7 The Contorted Drift
6 The Pebbly Sand and Pebble beds (Lower Glacial)
5 The Chillesford beds (Clay and Sand)
4 The Red Crag 4 The Fluvio marine Crag (Upper Crag)
3 The Coralline Crag (Lower Crag)
2 The London Clay
1 The Chalk.
Railways
Lines of Section A to W.
Broads
+ Denotes the position of the principal Parish Church of the places named. The position of every Parish Church is thus shewn, but in some few places where the shading is intricate the names have been omitted.
˥ Denotes a hamlet

Fig 3. Section of the map made by Wood, Jun. and Harmer showing the upper Tertiary formations of the Crag district including the Red Crag site in Bawdsey Cliff, Suffolk (Wood, Jun. and Harmer, 1872-1874).

On a visit to the Netherlands Harmer found that there was an area immediately south of the Hoek van Holland, which appeared to represent conditions prevailing in East Anglia during the Red Crag period, except with westerly rather than easterly prevailing winds. What was formerly a bay or inlet was nearly choked with shelly sand, which was still accumulating on the edges of the shoals, in channels formerly occupied by the River Maas, often bedded at a high angle, the stratification dipping in different directions as it followed the sinuous winding of the banks. Such evidence of major changes of wind flow since the Pliocene epoch led Harmer to his pioneer reconstruction of past circulation patterns and the study of palaeometeorology (see below).

Harmer suggested that there may have been, during the later stages of the Crag period, a gradual diminution in the salinity of the Crag Sea (proto-North Sea). This view, he continued, would also explain the decline of molluscan fauna in the succeeding Icenian deposits as compared with its great variety and abundance during the preceding periods. Harmer attempted to explain the increasing poverty and decreasing vigour of molluscan fauna of the Crag Sea during the Icenian period by proposing that the advance of the ice sheet from Scandinavia may have gradually obstructed this northern communication and eventually brought it to an end while fresh water continued to pour into it from the south. An influx of fresh water from the south under such circumstances, especially during summer, would have brought into existence a lake, the water of which became increasingly brackish. Some such cause as this may have changed the character of the Pliocene molluscan fauna of the Crag Sea and finally have exterminated a great part of it. Although communication with the Atlantic Ocean was subsequently re-established by the cutting of the Strait of Dover, the molluscan fauna of the East Anglian region has never regained the richness and variety it possessed during the earlier stages of the Pliocene epoch (Harmer, 1914-1919; 1920-1925).

The identification of the Red Crag formation by Edward Charlesworth in 1835 as a separate stage of the East Anglian Crag was followed by studies of later geologists, including Harmer, into this Pliocene formation (Reid, 1890). Wood, Jun., for example, regarded the shell-beds of Walton-on-the-Naze, comprising strongly-marked southern molluscan fauna, as being the oldest of the Red Crag deposits, and grouped the remainder of the formation, in which northern shells occur more or less abundantly, under the names of Suttonian and Butleyan. Joseph Prestwich, on the other hand, maintained that all of the Red Crag beds were contemporaneous. In view of these differences of opinion, Harmer decided to re-examine the subject to determine, if possible, a more definite conclusion. Accordingly, he spent five or six years revisiting every part of the Crag region, as well as examining the more important Crag fossil collections with the intention of obtaining evidence to establish the correct classification of these beds.

As a result of his research, Harmer subdivided the Red Crag into three formations on the basis of their fossilized molluscan fauna, namely, Waltonian, Newbournian and Butleyan. These formations, he suggested, indicated the progressive retreat northwards and cooling of the Red Crag Sea, with an ever-increasing proportion of boreal mollusc species. For example, the southernmost exposures of the Red Crag, particularly at Walton-on-the-Naze (appropriately assigned to the Waltonian formation), were considered by Harmer to represent the oldest Red Crag stage containing the warmest water faunas, including many species that are rare or absent elsewhere in the Red Crag, whilst the Newbournian and Butleyan formations outcropping further north probably indicated cool temperate conditions.

Limit of Glaciation

Despite earlier suggestions of glacial action occurring south of the Thames in the Weald and on the South Downs, it later became clear that evidence of glaciation was confined to north of the river. Harmer supported this idea and stated that the Younger or Eastern Drift, a characteristic till occurring at elevations of less than 100 m in Essex and associated with an advance of an ice sheet from the northeast, only extended south as far as the London Basin (Harmer, 1904).

The Origin of Certain Cañon-Like Valleys

When Harmer discussed the glacial origin of some gorge-like valleys in England, he suggested that such cases must be typical and not anomalous. Harmer continued that in all glaciated regions, whether in Britain or abroad, the invasion of any region by an ice sheet, especially where its movement was upstream, would obstruct the natural drainage, producing lakes in which levels would have risen until an outlet for the water was established in some new direction. In this key paper, Harmer presented the hypothesis that certain gorges in England might have originated as spillways due to the blocking of the previously normal line of drainage by an ice sheet (Harmer, 1907).

Harmer's hypothesis was referred to later by Leonard Wills when he suggested that the Upper Severn drainage was added to that of the Lower Severn due to the impounding of a glacial lake in Shropshire and Cheshire which rose until it flowed out over the former watershed between the Shropshire Plain and the headwaters of a tributary of the Worcestershire Stour (Wills, 1924).

In 1947, Sherlock also referred to Harmer's hypothesis, when discussing gaps in the Chiltern Hills. Sherlock suggested that an ice sheet advancing from the north during the Pleistocene impinged on the Chiltern Hills escarpment but was not able to override it in the Wendover-Tring section. With the waning of the ice, massive floods of water were released forming a lake between the hills and the retreating ice. The waters of this lake rose until their level reached cols in the escarpment where Wendover and Tring stand today. Here they overflowed into valleys with torrents of great erosive power on the dip-slope of the Chiltern plateau cutting deep steep-sided gorges very rapidly into the soft chalk – fully vindicating the hypothesis suggested by Harmer forty years earlier (Sherlock, 1947).

Amstelian Period

Amstelian was a term given to a now abandoned Quaternary stage that covered a period which more or less coincided with the Praetiglian (2.6 to 2.4 million years ago). The Amstelian is historically important because with its introduction by Harmer in 1896 a severe cooling had been established for the first time in the Netherlands by means of marine faunal assemblages. This drop in temperature was apparent from the fossil molluscs that had been found by the Dutch geologist, Jan Lorié in a series of deep boreholes made near Amsterdam.

As Harmer was recognised as the authority on Pliocene fossil molluscs in England, Lorié had sent him papers on the subject. From Lorié's descriptions of the fossil content of the strata, Harmer noticed the presence of boreal and extinct molluscan species which although he knew had occurred in England had not, up to then, been found in the Netherlands. He, therefore, proposed to introduce a new geological stage and, on the suggestion of Lorié, this became known as the Amstelian:

The name Amstelian, suggested to me as an appropriate one by Dr Lorié, is taken from that of the river Amstel, upon which stands the city of Amsterdam, where these beds have their greatest known development' (Harmer, 1896).

Searles Valentine Wood, Junior

Harmer's meeting by chance with the distinguished geologist, Searles Valentine Wood, Junior on Mundesley beach and their following friendship proved to be most valuable for Harmer by enhancing his geological studies. The son of the equally renowned geologist, Searles Valentine Wood, Senior, the younger Wood is generally recognised for establishing the systematic study of glaciology in East Anglia and was convinced that many of the problems of glacial geology could only be effectively resolved by mapping its deposits, an undertaking which, up to that time, had never been attempted in England – let alone in any other country. The following six or seven years were devoted to a more thorough study of those deposits in conjunction with Harmer who took up the challenge of his new colleague with characteristic zeal and industry and together they undertook a large-scale research study devoted to mapping the distribution of Pliocene and Pleistocene deposits in eastern England, Wood dealing with the drifts of Suffolk and Essex and his friend those of Norfolk.

During their period of investigation they traversed over 10,000 miles with every significant section in the region being examined. The area covered extended from the Norfolk coast as far as the Wash in the west, and south to the River Thames, thus comprising nearly all of the three counties, Norfolk, Suffolk and Essex. They embodied the results of their study in a memoir, *An Outline of the Geology of the Upper Tertiaries of East Anglia* (Fig. 4) together with a map and various sections of the Crag District (Wood, Jun. and Harmer, 1872-1874), the whole memoir being included in the publication, *Supplement to the Monograph of the Crag Mollusca, with Descriptions of Shells from the Upper Tertiaries of the East of England*, which remains one of the classic texts in the literature of geology (Wood, Sen., 1872-1874).

Unfortunately, further studies of the Pliocene and Pleistocene deposits of eastern England by Wood, Jun. were arrested by his failing health. Nevertheless, he was able to show by means of an original map published in 1880, four years before his death, the extent of the area covered by Chalky Boulder Clay in East Anglia. The notable map was also used by Harmer to illustrate his own paper about the glacial deposits of Norfolk and Suffolk published in 1910.

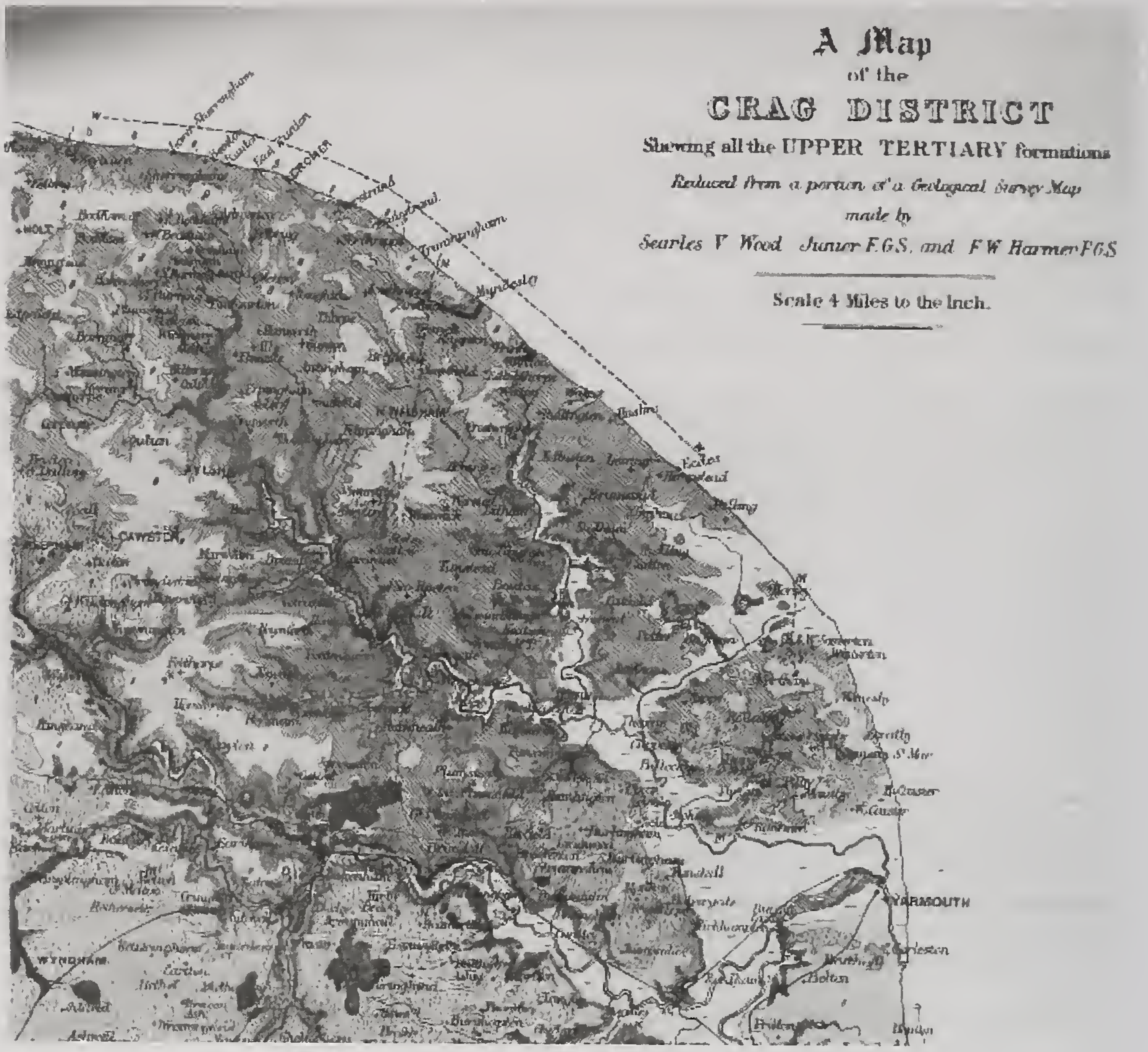

A Map
of the
CRAG DISTRICT
Shewing all the UPPER TERTIARY formations
Reduced from a portion of a Geological Survey Map
made by
Searles V Wood Junior F.G.S. and F.W. Harmer F.G.S
Scale 4 Miles to the Inch.
CROMER
HOLT
CAWSTON
WYNDHAM
YARMOUTH

Fig 4. Title page of the map made by Wood, Jun. and Harmer showing the upper Tertiary formations of the Crag district (Wood, Jun. and Harmer, 1872-1874)

Sadly, the loss in 1884 of his friend and scientific associate was a blow which adversely affected Harmer's enthusiasm for geological research and, for a time, he devoted himself more to municipal duties and local politics. However, although he had been deeply upset by the loss of his friend, about ten years later when, at the age of 60, he might well have felt entitled to enjoy his retirement, Harmer resumed an intensive study of the Pliocene and Pleistocene deposits of East Anglia and mainland Europe on discovering that his views had found a sympathetic hearing among a younger generation of geologists.

RENEWED GEOLOGICAL RESEARCH

In 1902 Harmer was requested by the Geologists' Association to prepare a résumé of his views on the later Tertiary deposits of eastern England; the resulting paper, based on observations made on a long excursion from 26 July to 4 August that year, inaugurated a new chapter in the geology of the region.

Coralline Crag, the oldest of these deposits, is made up of fragmentary polyzoa, sea-mats and related species, formerly termed corallines. In other parts of the Crag beds there are immense numbers of molluscan shells, warm water species indicating that in earlier times a sea channel was probably open through central Europe to warmer waters. The Red Crag follows in the geological succession and shells of a northern origin become increasingly more numerous at the expense of southern ones. Further north, the Norwich Crag, which rests directly on the Chalk, was believed to be part of the deltaic deposits of an early Rhine which flowed into the Crag Sea in the region of Cromer today (Harmer, 1902).

Also during the 1900s, Harmer took on the task of addressing a general oversight in the search for evidence of glaciation in southern England by traversing the region from the Humber to the Thames and from the East Coast to the Welsh Border in his new motor car. He remarked:

> *Most of the area over which the glacial ice is supposed to have passed has been examined personally by myself with more or less care with the aid of a motor car. During several of the excursions I had the advantage of being accompanied by the late J. Lomas, Dr R.H. Rastall, Mr G.H. Slater, and Professor P.G.H. Boswell, and on one occasion by Professor P.F. Kendall.*

Harmer recognised that these later investigations were 'rendered possible to an old man by the fortunate invention of the motor car, which literally gave me a new lease of geological life for field work'. In the early 1900s, people who had the means and need, replaced their horse-drawn carriages with chauffeur-driven motor cars.

Harmer thus acquired a personal and intimate familiarity with glacial deposits such as was probably possessed by no other observer of his time. The opportunity to examine geological sites available both in his earlier studies and those during the latter part of his life would perhaps never recur again due to their ever increasing loss during the following years.

Palaeometeorology

The attainment of the earth's landmasses and oceans into a favourable pattern for glaciation occurred in the Tertiary period and progressive cooling, which eventually led to the Pleistocene glaciations, set in during the middle and late Miocene epoch. The steady northward drift of the proto-European continental landmass contributed further to the history of cooling in that region.

As with his innovative ideas in the business world, Harmer's application of palaeometeorological methods to geology again illustrates his pioneering endeavours whether in industry or science. He was convinced that climatic changes during the Pliocene and Pleistocene were linked to long-term variations in atmospheric circulation which could be best investigated by reconstructing past circulation patterns.

He questioned that although in speculations about the causes of anomalous past climates, especially those of the Pleistocene, geologists had recognised the crucial role played by ocean currents, as well as the influence of winds upon the latter, they had seldom questioned how climatic changes may have also been due to variations in the wind flow itself, that is, by changes in past circulation patterns.

Harmer believed that by combining findings of geology and meteorology, past circulation patterns could be determined which would provide a scientific method for solving certain geological problems. Anomalous past climates, he stated, could only have occurred when atmospheric situations prevailed which were different from those normally experienced in the present period.

His attention had been drawn to this subject by chance when endeavouring to solve an outstanding geological problem, namely the meteorological conditions under which the Crag deposits of East Anglia had been laid down. Some of these beds originated as littoral accumulations during the Pliocene on the western margins of the Crag Sea (proto-North Sea). Comprising a mixture of sand and molluscan shells these deposits are found in a more or less continuous belt in the cliffs of the East Anglian coast; two million years ago or so the shore-line of the Crag Sea had extended farther west than that of the present North Sea.

Harmer was particularly interested in the Red Crag formation which comprises a succession of beds varying in thickness up to about 6 m (20 ft) with laminae of sands and shells inclined at a high degree to the horizontal. He realised that the molluscan shells of these deposits are seldom found today on the shores of the region and that one may walk for miles along the beaches of East Anglia without finding more than a chance specimen. However, this is not due to any absence of such molluscan life in the adjoining sea which Harmer, assisted by his son, Sidney, had ascertained by dredging.

Accordingly, he inferred that the meteorological conditions under which the late Pliocene Crag was deposited must have differed from those prevailing today and suggested that easterly rather than westerly winds may have prevailed over eastern England and the southern North Sea in the earlier period. Investigating the matter further, he ascertained, during a visit to Holland, that the beaches there were, in places, plentifully strewn with molluscan shells, probably comparable in amount and extent with those that had accumulated in East Anglia during the late Pliocene. Harmer was aware that in the present period Atlantic depressions which approach western Europe mostly travel east over the North Sea between eastern England and Holland. As a result, strong westerly winds and rough seas which generally prevail in the southern sector of these low pressure systems would frequently affect the Dutch coast.

The climate of the Pliocene appears to have undergone gradual refrigeration, as indicated by changes in the molluscan fauna of the Crag Sea. Harmer noted that although species were characteristically southern during the early Pliocene (resembling those of the Mediterranean in the present period) the sea was gradually invaded by boreal mollusca which eventually completely supplanted the southern fauna in the Red Crag as the climate became cooler on the approach of the Pleistocene glacial period. He found, for instance, the species now only found north of the Arctic Circle, became established in the proto-North Sea as far south as 52°N.

Harmer speculated that the climate of regions lying north of the British Isles during the late Pliocene probably became considerably colder than today as ice sheets and snowfields were established over Scandinavia – leading to the formation of permanent anticyclones. Under such conditions Atlantic travelling depressions approaching the British Isles would have taken a more southerly track than those of the present period with stormy weather and strong easterly winds frequently occurring over eastern England and the southern North Sea.

He graphically described how such conditions might have affected northeast Essex (Fig. 5) where he had spent several years carrying out field studies (Fig. 6) of the Red Crag:

It is not difficult to understand, when standing on the cliff at Dovercourt, looking out to sea over the bay formed by the projecting headlands of Walton-on-the-Naze on one side, and of Felixstowe on the other, that it would need only the prevalence of strong easterly winds to reproduce there the conditions of the Red Crag period. Were the direction of the winter gales which now drive vast quantities of sand and dead shells on to the shores of Holland, turned towards Essex, the mud flats of Dovercourt Bay would soon become silted up with shelly sand, as was that of the Waltonian region at a former period.

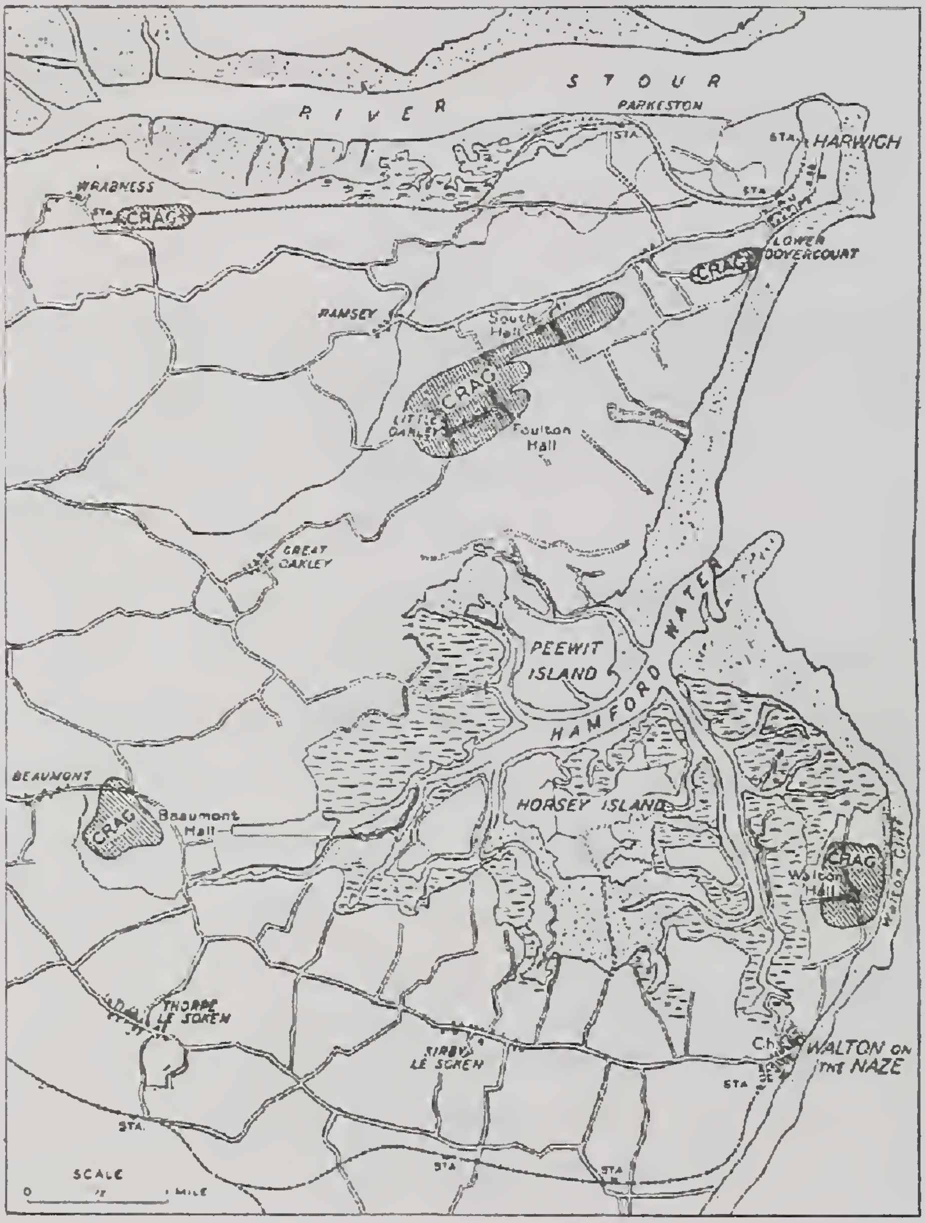


Fig 5. Map of Waltonian Crag at Little Oakley, Essex, showing Pliocene deposits. Further SE the cliffs at Walton-on-the-Naze expose some of the best – known and most accessible of these deposits in E England (Harmer, 1900a).

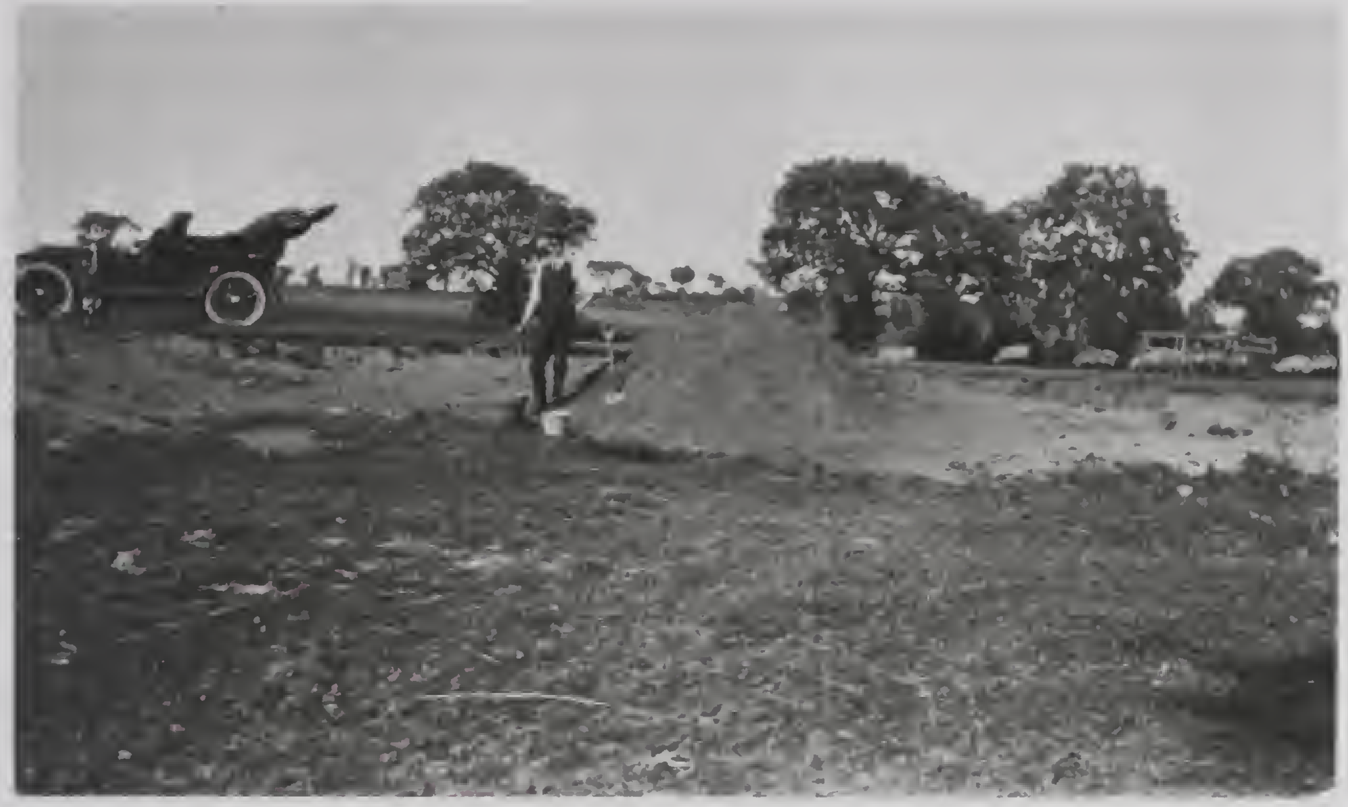


Fig 6. The pit of Waltonian Crag, Little Oakley, NE Essex. Harmer obtained shells of about 650 species of mollusca, as well as 100 or so specimens of polyzoa. His chauffeur appears to have been digging out the Crag material for sorting. Image P680273, F.W. Harmer collection, available on the British Geological Survey 'GeoScenic' website: CP13/076, Reproduced courtesy of the British Geological Survey © NERC. All rights reserved.

Through his studies of the Tertiary and Quaternary epochs Harmer became interested in palaeometeorology and pioneered the reconstruction of past circulation patterns, a most valuable tool in meteorological research by providing a synoptic view in time of atmospheric behaviour. He was convinced that long-term variations in the general circulation would have given rise to the major changes of climate that occurred during both the Pliocene and Pleistocene epochs.

He suggested that the anticyclonic pressure patterns which first developed over Scandinavia in the late Pliocene and later extended across the British Isles and northern Europe during the Pleistocene may be compared, but on a different time-scale, with the cold semi-permanent anticyclones which form in winter during the present period over the continental regions of northern Eurasia and North America.

In 1901, Harmer published a landmark article on palaeometeorology in the *Quarterly Journal of the Geological Society*, 'The influence of the winds upon climate during the Pleistocene Epoch: A palaeometeorological explanation of some geological problems'. This paper was one of the few dealing with palaeometeorology published in geological journals up to that time, which, in Harmer's case, indicated how certain problems in geology could possibly be resolved by means of meteorological methods. He believed that advances made in meteorology during the late 19th century in weather analysis could be adapted to resolve such questions (Harmer, 1901).

Unfortunately, Harmer's lead in the reconstruction of past circulation patterns was not followed through during the early 20th century and it was only in the 1960s that Hubert Lamb in the U.K. Meteorological Office and later the Climatic Research Unit, University of East Anglia reintroduced the concept of applying mapping methods to the study of climatic change (Lamb, 1966).

To highlight his approach, Harmer published selected charts illustrating his reconstruction of circulation patterns for the winter and summer seasons during the maximum glaciation of Europe about 18,000 years ago (Figs. 7 and 8) when northern and central parts of the British Isles were covered by a thick and extensive layer of ice (Kington, 2010). By means of these charts he inferred that travelling depressions, which at present generally move west-east over the Atlantic towards Europe, must have taken a south-easterly track more frequently than today due to the blocking effect of persistent and strong anticyclonic patterns over Scandinavia and adjacent areas. Also, he showed that the sub-tropical high pressure belt, which today prevents moist winds from the Atlantic blowing over the Saharan desert region, moved equatorwards. Consequently, with presumably increased rainfall occurring in lower middle latitudes and the subtropics, a humid climate prevailed over regions now affected by drought. It had been long known, as acknowledged by Harmer, that the Saharan desert region, which today has a virtually rainless climate, formerly experienced comparatively humid conditions during the Pleistocene epoch. Harmer's charts also corroborate the present concept of an expanding and contracting circumpolar vortex of the Northern Hemisphere in cold and warm periods respectively during and since the Pleistocene Ice Age.

It is noteworthy that by graphically indicating prevalent storm tracks and wind directions on his charts, Harmer presented a more dynamic approach to the reconstruction of past circulation patterns than with those later made by Lamb.

A comparison of the Harmer and Lamb reconstructions of winter and summer circulation patterns during the maximum glaciation in the Northern Hemisphere during the Pleistocene brings to light notable points of interest in the two independent attempts to reconstruct past pressure patterns. It is regrettable for the development of climatic research that there has been a hiatus of sixty years or so between these two studies.

Harmer's analysis of his winter chart (Fig. 7) shows a large blocking anticyclone over Scandinavia which extended west over Greenland and southwest over the British Isles resulting in an east to north-easterly wind flow over the latter region; another large anticyclone is situated over Asia. The track of the travelling depressions over the Atlantic divides into two branches mid ocean with one branch proceeding northeast into central Europe and the other east over the Mediterranean. This flow reflects today's finding that a general displacement of the zonal circulation towards lower latitudes occurred during the glacial period and supports the circulation pattern reconstructed by Harmer.

Lamb's analysis of his winter chart (Fig. 9) shows an anticyclonic centre over Scandinavia comprising an outlier of the high pressure system over the Arctic basin and like Harmer's chart another large anticyclone is situated over Asia. An extensive belt of low pressure over the Atlantic extends east across the Mediterranean to the Caspian Sea.

Harmer's analysis of his summer chart (Fig. 8) shows a large blocking anticyclone over the Norwegian Sea covering Scandinavia and much of Greenland, again with an easterly flow over the British Isles. The track of the travelling depressions over the Atlantic now divides into two branches off Iberia with one branch proceeding northeast into central Europe and the other east over the Mediterranean and then via the southern Black Sea into a large area of low pressure over Asia again probably related to the southward shift of the zonal circulation.

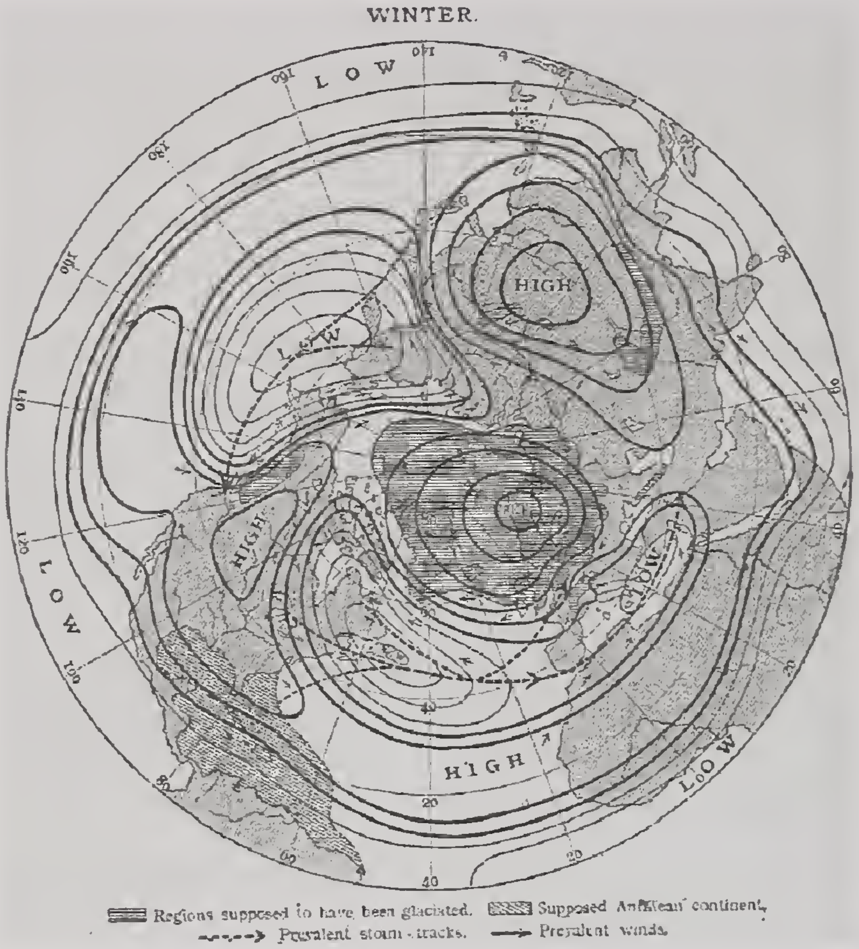


Fig 7. Harmer's reconstruction of the winter circulation pattern during the maximum Quaternary glaciation in the Northern Hemisphere (Harmer, 1901).

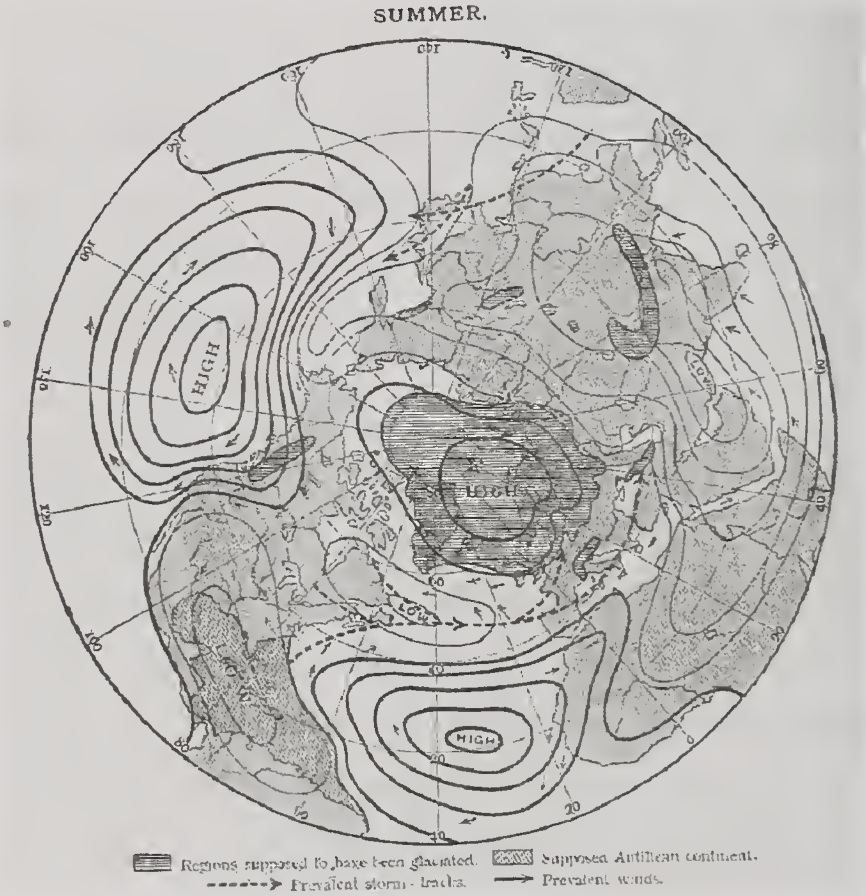

SUMMER.
HIGH
HIGH
LOW
HIGH
Regions supposed to have been glaciated.
Supposed Antillean continent.
Prevalent storm-tracks.
Prevalent winds.

Fig 8. Harmer's reconstruction of the summer circulation pattern during the maximum Quaternary glaciation in the Northern Hemisphere (Harmer, 1901).

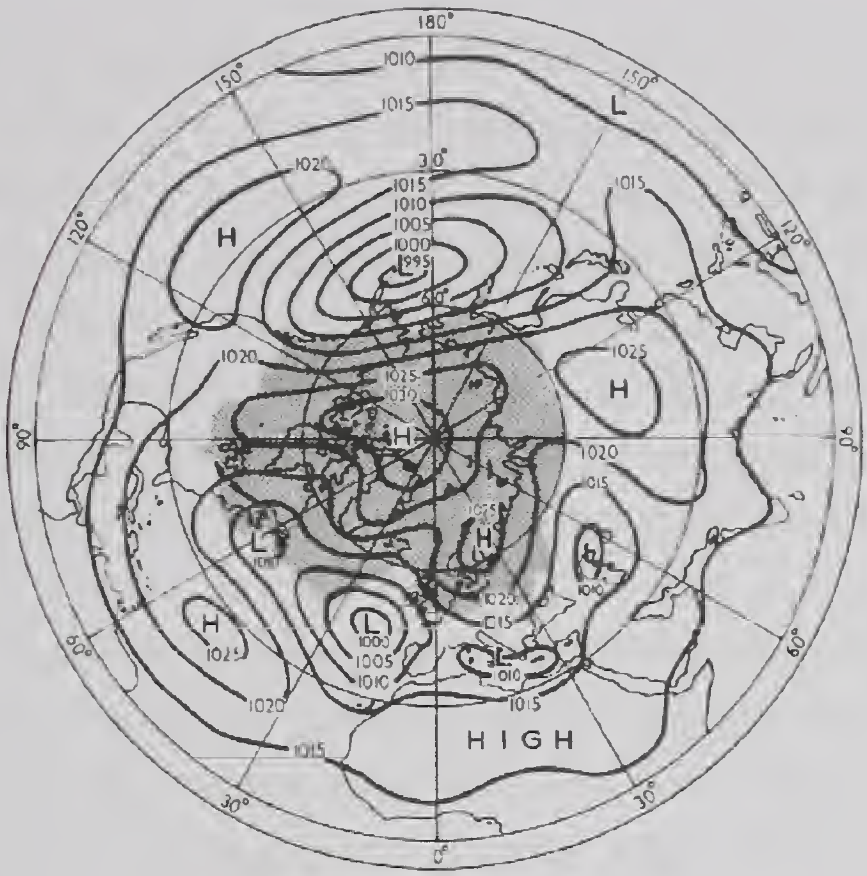


Fig 9. Lamb's reconstruction of the January circulation pattern during the maximum Quaternary glaciation in the Northern Hemisphere (Lamb, 1966). Ice sheet shaded.

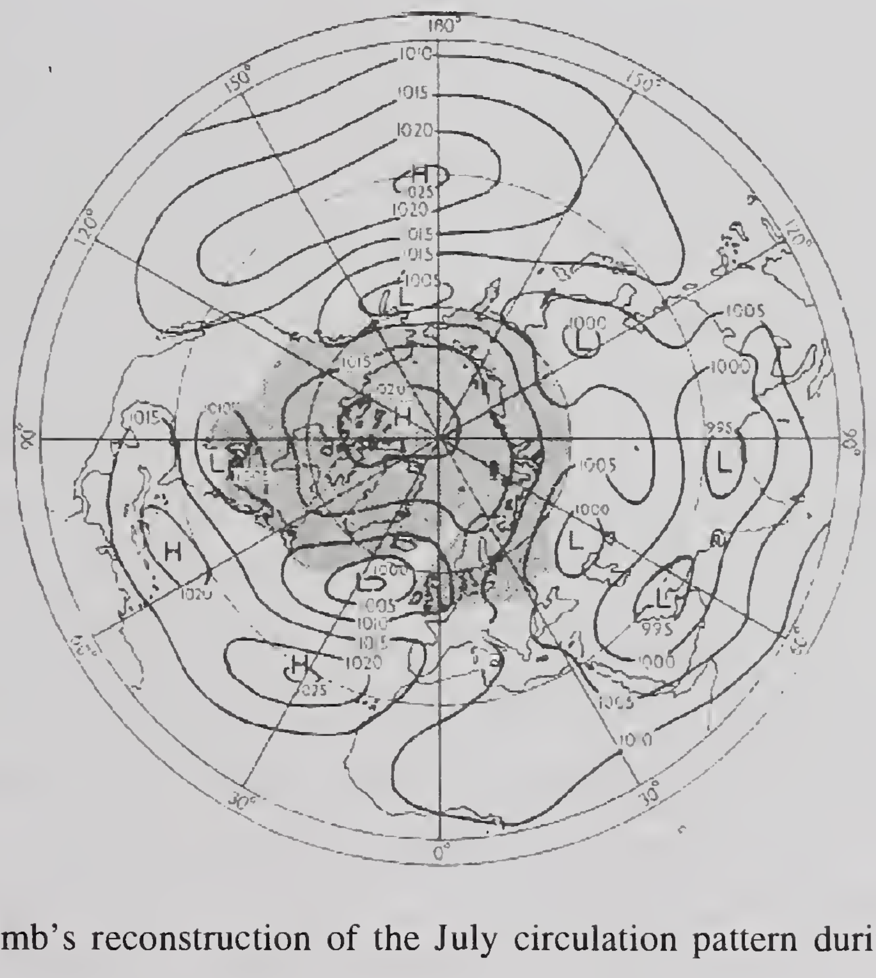


Fig 10. Lamb's reconstruction of the July circulation pattern during the maximum Quaternary glaciation in the Northern Hemisphere (Lamb, 1966). Ice and snow cover shaded.

Harmer's charts clearly show that there was less change in the character of the circulation from winter to summer than today, with the persistent blocking anticyclonic pressure patterns over Scandinavia in control of the overall situation in both seasons during the maximum glaciation.

Lamb's analysis of his summer chart (Fig. 10) shows an extensive anticyclone over the Arctic basin with a ridge extending towards northern Scandinavia. A multi-centred area of low pressure is situated over Asia with outlying centres over Europe and off southwest Iberia. Another low pressure system occurs over the eastern North Atlantic.

Lamb concluded that two of the main features of his reconstructed pressure patterns were firstly, an intensification of the circulation, especially in summer, both of the mid latitude westerlies and the Trade winds; and secondly, like Harmer, a general displacement equator-wards of the zonal circulation. Furthermore, he added, it was likely that the winter circulation in higher latitudes over the ice sheets was weaker than today and, following Harmer, that there was less change in the character of the circulation from winter to summer than now.

Harmer stated that the great extension of Swiss glaciers during the Pleistocene epoch indicated that considerable masses of moisture-laden air must have reached the ice fields from maritime sources mostly from the west. Also travelling depressions moving eastward from the Atlantic, as suggested in his summer chart, may have occasionally affected south-western parts of Europe. He continued that the climate of the region north of the Swiss massif was colder at this period that that to the south of it, the former having been more or less under the influence of anticyclonic winds proceeding from the ice sheets of northern Europe. While ice was steadily accumulating in the north, the sun's heat during summer on the southern slopes of the ice-clad Alpine mountains together with the rains that may have fallen there, produced violent floods which inundated the lowlands of Piedmont and Lombardy from the foot of the Alps to the Adriatic leaving a thick and continuous deposit of diluvial gravel and mud.

It is only when standing on the tower of the Cathedral at Milan, or on the summit of the Superga, near Turin, looking across the great plain towards the distant mountains rising abruptly from it, that one can realize the strength and volume of the torrents which must have issued from the Alpine valleys at this epoch (Harmer, 1901).

One of the effects of strong winds associated with stormy weather over the North Sea is to agitate the water to a considerable depth and to scour the sea-bed, causing molluscan shells to be shifted towards the opposing coast. Harmer learned from a colleague in Great Yarmouth that on 12 or 13 December 1899, the local beach, on which shells were not usually found, was partly covered by them. By referring to the *Daily Weather Reports* of the Meteorological Office, Harmer found that a spell of strong to gale force east to south-easterly winds had occurred from 7 to 9 December which caused many shells to be thrown up on the beach.

He used this meteorological situation, associated with a blocking anticyclone over Scandinavia as an analogue for the type of circulation pattern which, he suggested, had frequently occurred during the late Pliocene leading to the formation of a succession of littoral beds, which, in the case of the Red Crag, attained a thickness of 6 m (20 ft) or so in the cliffs of East Anglia.

In summary, Harmer's hypothesis suggested that anomalous circulation patterns associated with current weather extremes over the British Isles may have been the norm in past geological periods such as the late Pliocene epoch when shelly marine sands, collectively known as Crag deposits had massively accumulated near the western shoreline of the Crag Sea, due to the successive drifting of the material upon the beach by strong and persistent easterly winds.

In 1925, two years after the death of Harmer, his later paper on the same subject, 'Further remarks on the meteorological conditions of the Pleistocene epoch' was presented at a meeting of the Royal Meteorological Society by the climatologist, Charles E.P. Brooks who explained that this article was essentially an amplification and extension of the views first advanced by Harmer in his 1901 paper. Harmer's son, Sir Sydney Harmer, who attended the meeting, explained that he had found the manuscript in his father's collection and was greatly indebted to Brooks for preparing the paper for publication (Harmer, 1925).

The palaeometeorological research of Harmer was again presented to the Royal Meteorological Society by the geologist Percy G.H. Boswell in the G.J. Symons Memorial Lecture on 17 April 1940. Boswell called attention to the general principle that anomalous meteorological situations in the past, even if more or less permanent, may have been due to the same cause which brings about temporary changes of a similar character in the present period, namely, variations in circulation patterns. Boswell continued that Harmer appeared to have been drawn to consider this concept through his studies of the Pliocene shell beds, or Crags of East Anglia. In his efforts to interpret the conditions under which these shallow water deposits were formed, Boswell reiterated that Harmer referred to similar deposits being accumulated in the present period on the Dutch coasts, especially when driven up the beaches by strong south-westerly winds. As a result, Harmer concluded that strong easterly rather than westerly winds had occurred during the Pliocene epoch, causing shells and other marine organisms to be torn from the sea bed and thrown up as detrimental accumulations on the eastern England shores of the proto-North Sea (Boswell, 1940).

Final Years

In the summer of 1922, one of Harmer's esteemed colleagues P.F. Kendall made 'a long desired visit to my old friend, F.W. Harmer. I found him in delicate health, as was not surprising in view of the fact that he was then in his 88th year'. Referring to the loss of geological sites, Kendall remarked that it was noticeable that increased industrial activities for road-making and building materials, especially in the concentration of large brick-works on outcrops of argillaceous formations, had resulted in the closure of hundreds of small excavations formerly used for geological digs, such as gravel-pits, chalk-pits and brickyards. Harmer also commented regretfully on the disappearance of such exposures for geological studies.

Two outstanding works undertaken by Harmer during the final years of his life, each entailing an immense amount of research, were firstly a detailed map showing the types of boulder clay and trails of erratics in England and Wales, and secondly a two-volume monograph on Pliocene Mollusca. This latter work, his *magnum opus*, was an achievement which will long earn the gratitude of later investigators and will always remain a most fitting monument to his memory.

In geology, Crag is the collective term given to the sandy, shelly Pliocene deposits which comprise the principal Tertiaries of East Anglia laid down about two million years ago under marine and later estuarine conditions. Patches of the Red Crag have survived in northeast Essex at Dovercourt, Beaumont, Wrabness and Little Oakley. In the 19th and early 20th centuries sand pits at these sites yielded fossils, one of the most well-known sites was a shallow pit at Little Oakley that was investigated by Harmer who over a number of years sifted and examined its sand for fossil shells. The shells of 650 different species of mollusca and about 100 specimens of polyzoa were found in this one pit alone (nearly 400 of the species illustrated in his monograph were from the Little Oakley pit).

Harmer's meticulous research has shown the extraordinarily rich molluscan fauna of the Crag Sea which existed over northeast Essex and East Anglia about two million years ago. He was aware that the Red Crag formation was deposited in near-shore conditions during the Pliocene as part of a large delta that was building out into the southern part of the Crag Sea which, at that time, extended into the London Basin as far west as Hertfordshire and Surrey, where a proto-Thames flowed into it. Although this Crag Sea or proto-North Sea was connected to the Atlantic across southern Britain it was not through the English Channel as it is known today. However, this early sea link was slowly reduced and by about two million years ago not only was it lost but the head of the delta between Britain and mainland Europe became dry land, now named Doggerland (after the Dogger Bank). As the shoreline moved northwards, so the proto-Thames and other major rivers such as the Rhine flowing into the Crag Sea extended across the former sea bed. The molluscan shells of the Red Crag indicate a cooling of the climate compared to previous stages and this formation is sometimes considered to mark the onset of the last Ice Age.

This is in accordance with the re-classification of the East Anglian Crags in the geological column whereby it has been generally agreed since Harmer's time that whilst the Coralline Crag should remain in the Pliocene, the Red Crag and Norwich Crag should be placed in the Pleistocene (Challinor, 1978).

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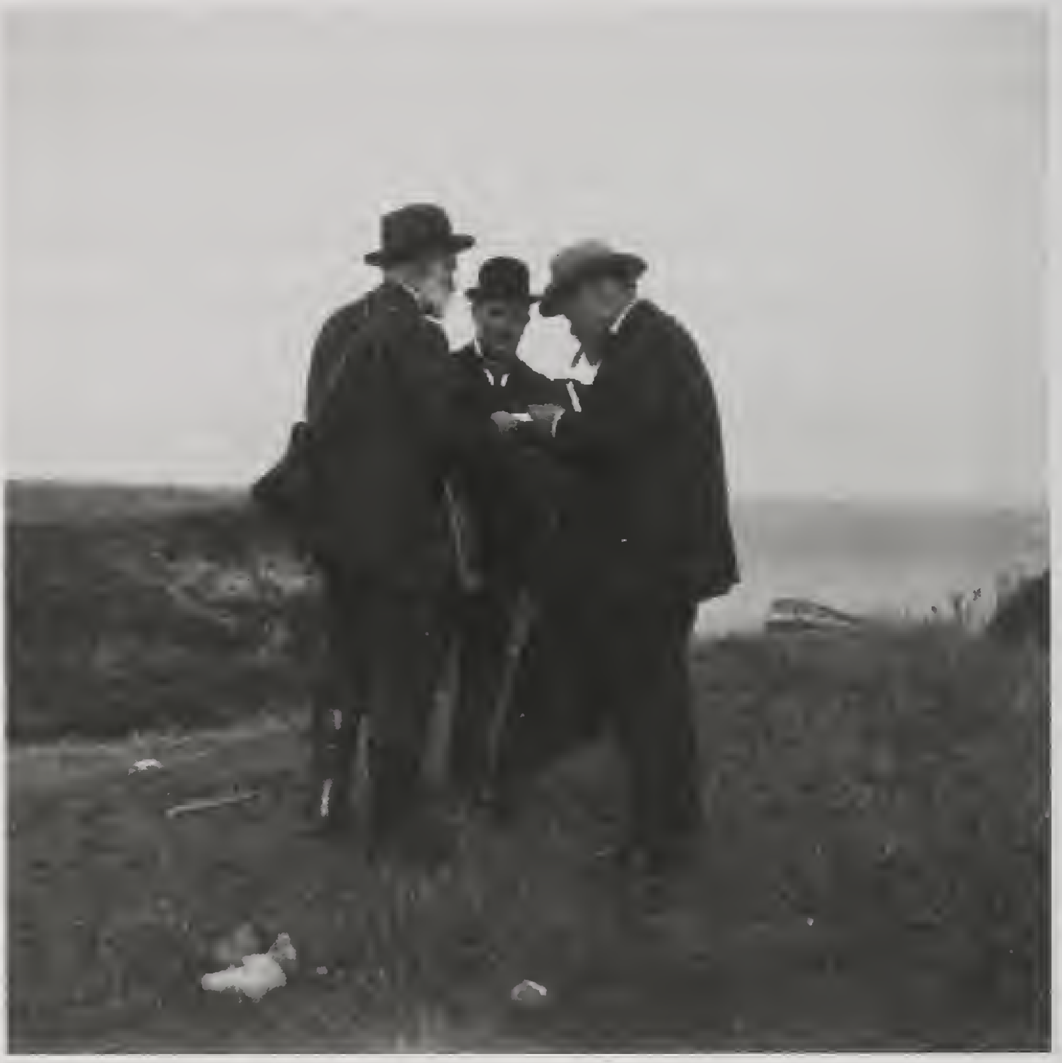

Photograph P680269 from the F.W. Harmer collection, British Geological Survey 'GeoScenic' website, entitled 'Above Runton Gap', East Runton cliffs, N Norfolk. Dated October 3 1907, Harmer is the figure on the left, accompanied by the German geologist Carl C. Gottsche and the Austrian geologist, Emil Tietze. CP13/076, Reproduced courtesy of the British Geological Survey © NERC. All rights reserved.

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WILLIAM SMITH IN NORFOLK AND SUFFOLK 1801-1818

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ABSTRACT

Smith's remarkable sea defences and drainage works in East Anglia coincided with a blossoming of the natural sciences here. Although he managed to publish some of his geological and biostratigraphical observations in the region, Smith characteristically had little contact with contemporary investigators who included world class taxonomists and the pioneering archaeological stratigrapher John Frere.

INTRODUCTION

William 'Strata' Smith (1769 -1839), 'the father of English geology' came to East Anglia during a propitious period. The natural sciences were flourishing in the region and the Board of Agriculture was seeking to add a geological dimension to its county-based surveys. Even more to the point, John Frere's stratigraphical account of the hand axes at Hoxne had just been published. The question then inevitably arises, how did Smith interact with these contemporary ideas and initiatives?

Smith had distinguished himself as a drainage engineer in the short time since his ambivalent dismissal from the Somersetshire Coal Canal Company in June 1799 (Torrens, 2003), and in 1800 Thomas William Coke (1752-1842) invited Smith to Holkham. Coke is best known as a major landowner and agricultural reformer, but he was also influential as the long-serving MP for Norfolk (1776-1784; 1790-1834) and became the Earl of Leicester in 1837. Smith arrived at Holkham in 1801 and his concerns in East Anglia ranged until 1834, although all his site work in the region was completed by 1818. As a surveyor/engineer Smith was employed mainly on coastal drainage and sea defence projects.

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From 1812 onward Smith also received drawings of East Anglian exposures and fossils from his one-time assistant, the Norfolk based surveyor Richard (Cowling) Taylor (1789-1851). All of this then informed Smith's publications, particularly his 'Great Map' of England, Wales and part of Scotland published in 1815. According to Phillips (1844, p149), in 1819 Smith published enlarged geological maps of both Norfolk and Suffolk, together with a section across the two counties. In the event, 1819 was the year in which Smith's debts forced him into prison before semi-retirement to Yorkshire and neither of these maps is now known even as a draft. However the Smith archive does contain (Box 14, item 6) Smith's apparently unpublished draft of geological sections across both Norfolk and Suffolk. Shortly thereafter Taylor himself began to publish geological sections across the region (Wood, 2000; Banham, 2012). Smith produced no further East Anglia-based works, apart from a feasibility study in 1818 of the proposed Diss (Waveney) Navigation, a job secured for him by the local influence of Taylor, and a short paper to the Edinburgh British Association meeting (1834) on 'Observations on the Waste and Extension of Land on the East Coast of England'.

The perception of Norfolk as distant may have been justified at that time, although on his first visit at least, Smith chose to walk to and from his home in Bath, on the way recording the geology and placing fossil finds under prominent trees for later collection (Phillips, 1844 p 35). However we can scarcely be expected to agree that for Smith Norfolk was 'a geologically rather unremunerative part of the country' (Torrens, 2003, p xxix).

EAST ANGLIA 1801-1818

Tensions arising from the war with France (1793-1802; 1803-1815) were always keenly felt in Norfolk, the county of birth both of the exiled radical republican Tom Paine (1737-1809) and of the nation's great hero Nelson (1758-1805). Political issues came to a head in 1802 when William Windham (1750-1810) of Felbrigg Hall, MP for Norwich since 1784, 'Secretary at War' in Pitt's government since 1794 and the Eton school friend of Thomas Coke the MP for Norfolk, was defeated in the parliamentary election by a radical also by the name of William Smith (1756-1835). Incidentally, Windham's losing running mate ('Second Member') was John Frere of Hoxne fame, of whom more below. This other William Smith remained MP for Norwich for many years thereafter (1802-06; 1807-1830), although with two more tension-raising elections during engineer William Smith's stay in Norwich. Throughout, the name William Smith would have had a very high profile, and no doubt led to banter with the county landowners who engaged our Smith.

Of more immediate importance for farmers and for Smith would have been the appointment of the agricultural experimenter and writer Arthur Young (1741-1820) of Bradfield, Suffolk as the Secretary of the London based Board of Agriculture (1793-1818). Young's chief task was to commission reports on farming county by county; naturally he himself undertook no fewer than three for Suffolk (1794, 1797 & 1804) and one for Norfolk (1804; Banham 2012). From 1804 Young produced sketch soil maps in his own reports and he attempted to involve Smith in adding a geological dimension to the Board's work. However, as we have seen, Smith was by then very busy in East Anglia; what is more, he apparently failed to grasp that he was required to present a proposal to the Board. Painfully for Smith, in 1807 the Board instead appointed Smith's 'first disciple', the talented John Farey (1766-1826) to report on Derbyshire, where the very influential Sir Joseph Banks and the Duke of Devonshire owned estates and lucrative mines.

Norwich was no longer the second city in the kingdom that it had been at the beginning of the eighteenth century (Meeres, 1998), but by Smith's time its main wealth producing wool industry had only partly transferred to Yorkshire and factory-based boot and shoe making had already begun. Also, given the active involvement of both Thomas Coke and Arthur Young, East Anglia had early benefits from improvements in agriculture. This past and present wealth laid the foundation for an important banking and insurance sector in Norwich. Religious dissenters, principally Unitarians and Quakers with a strong Huguenot component, were very influential in business and local politics. Whilst in Norwich, our William Smith took rooms at the Swan Inn, now long demolished, near St. Peter Mancroft church. This was a large and lively hostelry, no doubt something of a safety valve in serious times. Although a Theatre Royal had been open since 1758, the Swan Inn continued as a venue for performances and public events of all sorts, including cockfighting. There and elsewhere, no doubt Smith met many people beyond his usual client landowners and

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Whilst Smith was there, Norwich in particular was home to a galaxy of great scientific names. The botanist Sir James Edward Smith (1759-1828), FRS, FLS, was a leading figure; as a founder fellow of the Linnaean Society he had borrowed 1,000 guineas from his Norwich merchant father to make the controversial purchase in Uppsala of all the collections, books and archive of the great Linnaeus. In 1796 J.E. Smith left London to return to his native city to write further major botanical monographs and also several Unitarian hymns for the Octagon Chapel in Colegate. Another prodigious botanical collector and writer was the colourful and wealthy Dawson Turner (1775-1858) FRS. After Cambridge, in 1796 he joined the Yarmouth family bank of Gurney and Turner that was later incorporated into Barclay's. Although his early passion was botany, particularly the mosses, lichens and algae, his later interests were more diverse and included the liberal patronage of the contemporary Norwich School of painters that included Crome, Cotman and Stannard. Turner's daughter Maria married Norwich bank clerk William Hooker (1785-1865) who was also a protégé of Sir James Smith. In 1820, after leaving his father-in-law's bank at Halesworth, Hooker became the Professor of Botany at Glasgow University and then, as Sir William Hooker, FRS, FLS, the first director of Kew Gardens. Incidentally, Harriet, another of Dawston Turner's studious daughters, married the Revd. John Gunn (1801-1890) whose mid-century observations laid a sound foundation for later studies of the Cromer Forest Bed and of the glacial sequence. Gunn is also credited with co-founding the Norwich Geological Society in 1864. Meanwhile, Sir James Smith also encouraged the Revd. William Kirby (1759-1850), FRS, FLS, the Rector of Barham, Suffolk; known as 'the founder of entomology' Kirby is particularly remembered for his 1802 Linnaean Society monograph on English bees.

What of all this to our William Smith? These eminent naturalists were essentially taxonomists, and it is the rigorous identification and location of fossilised animals and plants that forms the basis of what we now call biostratigraphy. Smith had first recorded the basic principles of this new science early in 1796 at another Swan Inn at Dunkerton, beside the Somersetshire Coal Canal for which he then had engineering responsibility (Phillips, 1844 p17; Cox, 1942 p12). However, there appears to be no evidence that William Smith knew any of these scholars in the region.

In 1818 Sir James Smith was declined a chair at Cambridge, officially because he was a Unitarian, although there were murmurs of personality clashes. This break may have contributed to a shift of the scientific centre of gravity towards Ipswich. Existing links between Suffolk and Cambridge, including an early collaboration between Arthur Young and Professor John Symonds, were multiplied after 1839 when the Revd. Professor John Stevens Henslow (1796-1861) FRS, FLS and an early member of the Geological Society of London, became the Rector of Hitcham, Suffolk (Plunkett, 2012). The Ipswich Philosophical Society and the famous museum followed within a few years, not to mention the highly profitable coprolite based fertiliser industry also initiated by Henslow. Although he was Charles Darwin's tutor, friend and guide, like many another Henslow could not accept the concept of evolution, giving rise to much discussion. This in turn served to focus belated international attention on John Frere's work at Hoxne that had been published back in 1800, the year T.W. Coke had invited William Smith to Holkham.

JOHN FRERE, FRS FRA (1740-1807) AND STRATIGRAPHY

On the basis of a single short paper published in 1800 John Frere remains a major figure in archaeology and geology (Wymer & Singer, 1993; Wymer & West, 1999). If Smith and Frere had met, their stratigraphical discussions would have been by no means one-sided.

The Suffolk-born Frere was a Cambridge-trained lawyer who had no need to practise. However, he became a JP for Norfolk and Suffolk and served as High Sheriff for Suffolk. London-based until 1780 when he inherited Roydon Hall, near Diss, Norfolk, Frere became a Fellow of the Society of Antiquaries in 1795, around the time that he began to assist his brother-in-law (Sir) John Fenn of East Dereham with the preparation of the Paston Letters for publication in separate volumes from

1787 onward. As we have already seen, Frere became William Windham's running mate as an MP for Norwich in 1799. Despite a joint outlay of £8,000 they lost the election of 1802; Frere managed to deal with his share of this crushing debt, but he suffered a stroke and died not long after.

Fortunately before that excursion into politics, in 1797 Frere wrote a short letter to the Society of Antiquaries concerning the presence and context of numerous hand axes within the brick pit at Hoxne. Published in 1800, and reprinted in Wymer and Singer (1993), the paper tables the stratigraphical sequence and then describes each bed and its contents, including the spectacular hand axes and fossils of large mammals at one horizon, in a manner that biostratigrapher Smith could only have approved. More, in a thoroughly Huttonian way Frere went on briefly to interpret the processes and palaeoenvironments responsible for these beds and their relationship to the present landscape. As we have seen, this work was so advanced that it took several decades for its significance to begin to be realised. Fittingly, after further pioneering work by West (1956), the type site of the Hoxnian Interglacial Stage is now defined within this brickpit sequence.

By contrast, apart from his revolutionary biostratigraphical insights, Smith's own geological views are very much of the period (Cox, 1942, p69ff). He had little grasp of geological time and believed that 'stratification has resulted from a chemical conversion of liquids and gasses into the solid state...leaving shells and plants as extraneous substances of prior existence'. On the draft county cross sections in the archive Smith clearly shows the Crags above the Chalk and below the alluvium, but he was uncertain as to whether they were products of the Deluge, like the 'Diluvial clay' (presumably the glacial tills etc; Plunkett, 2012, p87f). Indeed, his very nickname 'Strata Smith' reflected the view of his contemporaries that he harped on about an old topic that had diverted the learned for over a century since John Ray had given it prominence (Fuller, 2004). These same scholars had nevertheless entirely missed, and many long after continued to deny, the fact of a correlation between individual fossil species and particular strata that was very apparent to Smith, the committed, keen eyed, widely travelled practical field man.

Apparently Smith knew nothing of Frere's work at Hoxne, but there is one possible link by way of the antiquary Henry Jermyn (1767-1810) of Sibton Abbey near Yoxford who compiled a detailed, but unpublished history of Suffolk. Smith had met Jermyn, his 'learned and good friend' (Phillips, 1844 p73), when he was involved with draining the Minsmere marshes for which Jermyn was a Commissioner. Later, when they were both in London, Jermyn helped Smith prepare his 'Great Map' for publication in 1815. Aside from a very detailed account of the history of Dunwich Haven, Jermyn's several letters to Smith between 1812 and 1815 mainly regret that he is not in a position materially to help with Smith's severe financial problems. So, any thought of their discussion of Frere's work is speculation. Furthermore, as we have seen, the multi-facetted significance of that work did not really begin to emerge until much later.

CONCLUDING REMARKS

On balance it seems likely that Smith knew little or nothing of the work of those eminent biologists, nor of Frere's stratigraphical insights at Hoxne. On the evidence of the archive at Oxford, Smith was much more concerned to promote geology in general and his own interests in particular. For instance, in a letter to his physician of October 17, 1805, Smith asks Dr. Rigby to come to the Swan Inn to treat a severe 'Rheumatic pain' in his hip and right leg. However, Smith begins the letter by saying that he 'hoped to have the great satisfaction of showing you my Maps of the Strata'. Likewise, a letter of June 20, 1818, to Smith from the banker botanist Dawson Turner, as chairman of the Waveney Navigation Committee apologising for a delayed decision, begins by thanking Smith for sending him a list of Norfolk fossils. As with Arthur Young's offer on behalf of the Board of Agriculture, Smith was apparently so self-driven that he failed to grasp the position of others. However, Smith's coastal drainage and sea defence works and his contributions to the palaeontology of the Upper Chalk and Crags are a tangible legacy of his time in East Anglia. Equally important, from 1810 Smith tutored and inspired the geological work of the Norfolk surveyor Richard Cowling Taylor. In 1830 Taylor left Britain to become 'the best of the early geologists of the United States' (cited in Torrens, 1999).

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As in so many aspects of geology, the late Brian Funnell led the way when he published in the precursor to this journal a comprehensive bibliography of early geological research in East Anglia. I am also greatly indebted to Mark Dickerson and Kathleen Santry of the Oxford University Museum of Natural History for providing electronic copies of documents in the William Smith archive of which they have been successive curators (see below).

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The William Smith Archive. Enquiries should be directed to the curator of the archive (now Kathleen Santry) at the Oxford University Museum of Natural History (OUMNH): kathleen.santry@oum.ox.ac.uk. There is a project in hand to provide online access to the archive.

Distinguished East Anglian Scientists and others. Full biographies can be found online in the (New) Oxford Dictionary of National Biography (2004) at www.oxforddnb.com. Members of public libraries can have free access to this resource via their own computers.

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The Geological Society of Norfolk exists to promote the study and understanding of geology in East Anglia, and holds meetings throughout the year. For further details consult our Web Site (http://www.norfolkgeology.co.uk) or write to Martin Warren, General Secretary of the Geological Society of Norfolk, Chesterfield Lodge, West Street, Cromer, Norfolk NR27 9DT.

Copies of the Bulletin (including older back copies) can be obtained from the editor at the address on p.1; it is issued free to members.

The illustration on the front cover is figure 2 from the article by Andrews in this issue of the Bulletin. It shows the Jurassic oyster-bearing erratic in the grounds of Oxburgh Hall, west Norfolk. The field notebook is 20 cm long.

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